AWT AERODYNAMIC DESIGN STATUS

MILT W. DAVIS

LEAD ENGINEER, AWT AERODYNAMICS

SVERDRUP CORPORATION

ALTITUDE WIND TUNNEL
FOR PROPULSION AND ICING RESEARCH

NASA LEWIS RESEARCH CENTER, CLEVELAND, OHIO

PRELIMINARY ENGINEERING REPORT
SECTION 2

TUNNEL AERODYNAMICS, PERFORMANCE
AND OPERATING COST

PREPARED BY
SVERDRUP CORPORATION
St. Louis, Missouri

FOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
CLEVELAND, OHIO
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The Team

Milt Davis

Jim Reed

Dave Boylan

Mike Varner

Bill Moger

Tom Barton

Bill Martindale

Grant Patterson

Keith Bailey

Wanda Floyd

Barbara Pennington

Bill Crouch, et al

25-PERCENT REVIEW, AWT AERODYNAMICS

MAIN ACTIVITIES

- ANALYSIS OF AN INDEPENDENT PLENUM EVACUATION SYSTEM (PES)
- AIRLINE DEFINITION AND PRESSURE LOSS CODE DEVELOPMENT WITH EMPHASIS ON THE DEVELOPMENT OF ALTERNATE COOLER AND BASELINE SCAVENGING SCOOP DESIGNS
- CONTRACTION GEOMETRY AND CODE ANALYSIS
- AERODYNAMIC DESIGN OF THE TWO-STAGE FAN USING THE REF. 1 DEFINED PRESSURE RATIO REQUIREMENTS
- COORDINATION AND COMMUNICATION

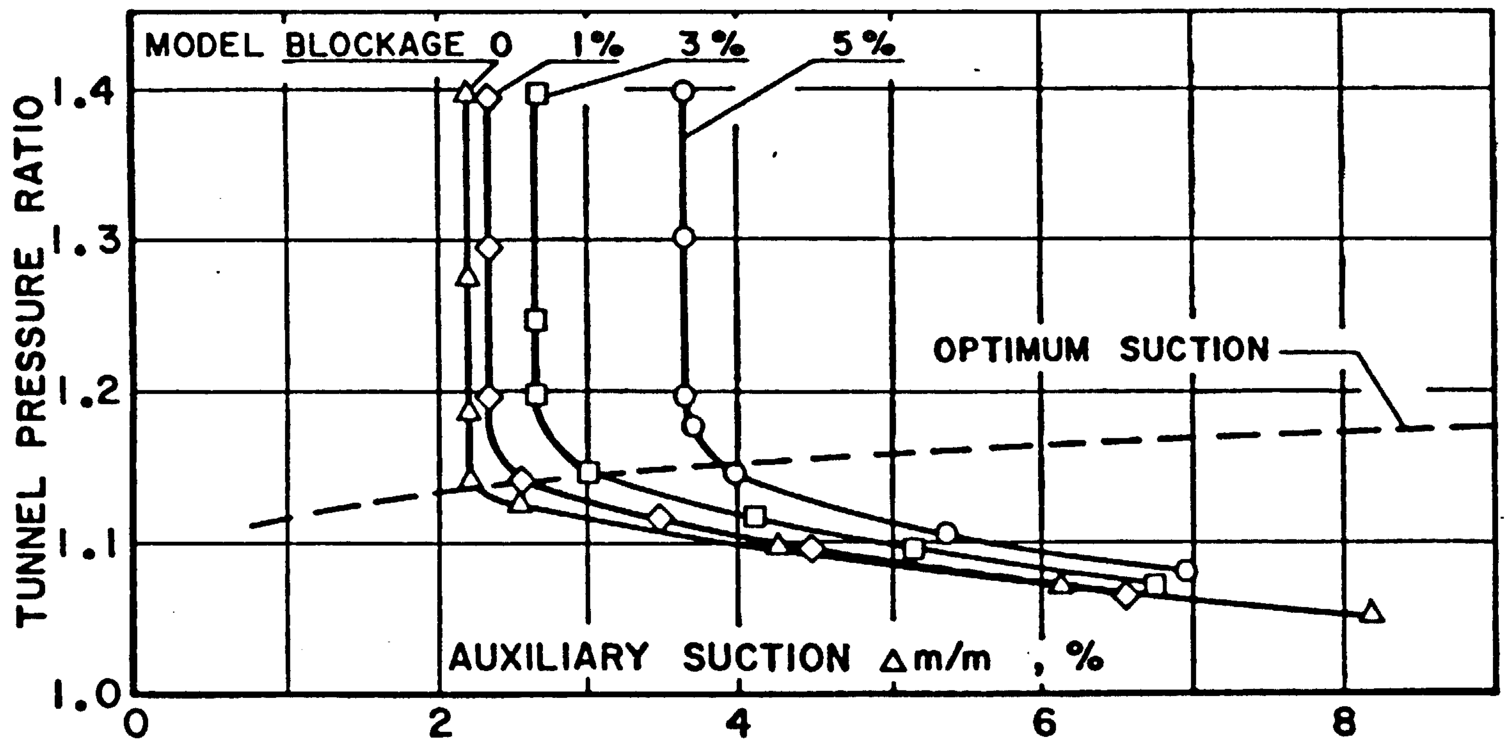
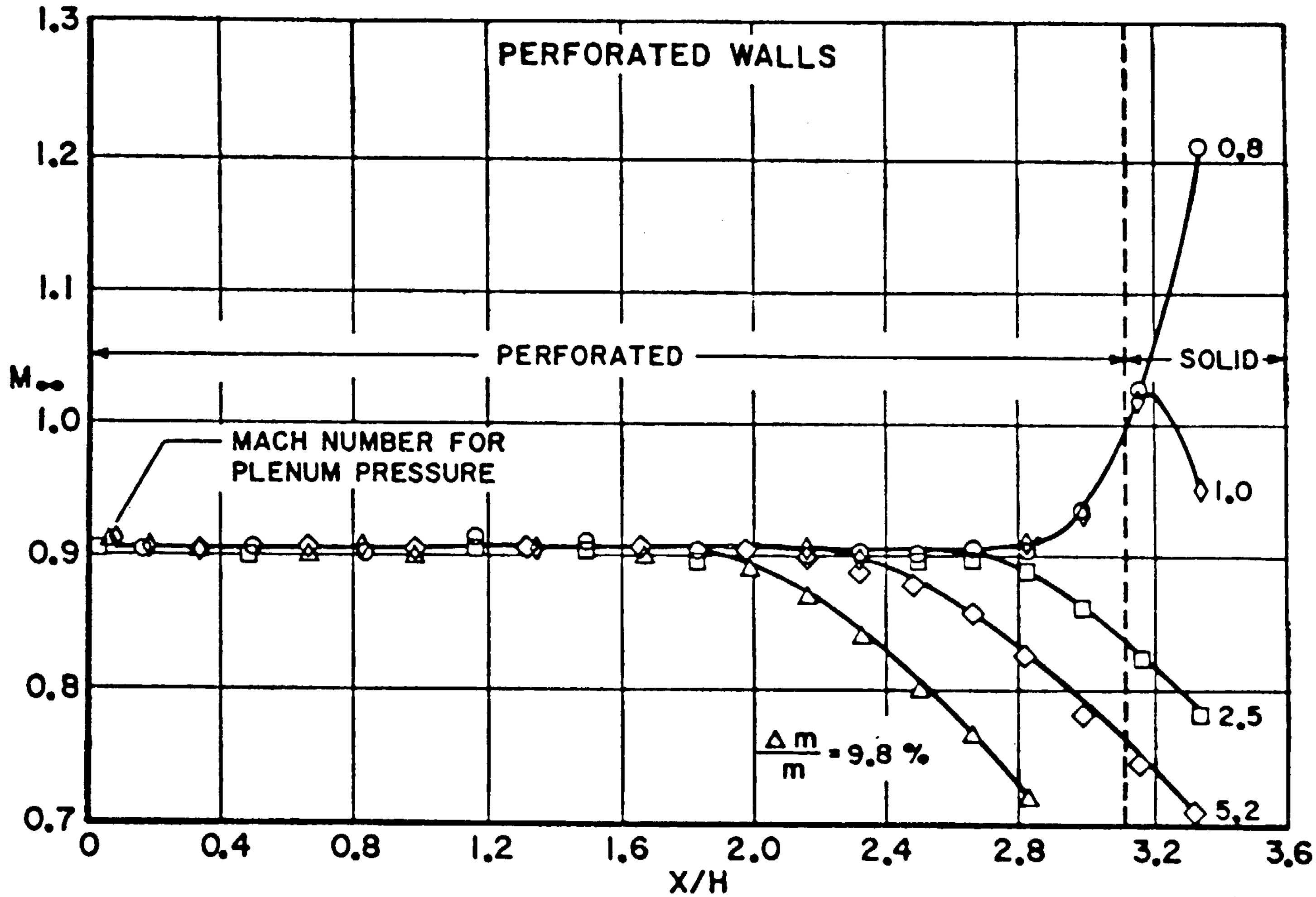


FIG. 14.13. *Influence of model size on pressure ratio and suction requirements of perforated wind tunnel at* $M = 1.0$ *(22.5 per cent open walls,* $\frac{1}{4}$ *in. holes, parallel walls) (AEDC 1 ft transonic model tunnel*[4]*).*

MACH NUMBER DISTRIBUTIONS FOR PERFORATED TEST SECTION WITH PARALLEL WALLS FOR VARIOUS PLENUM CHAMBER SUCTION QUANTITIES



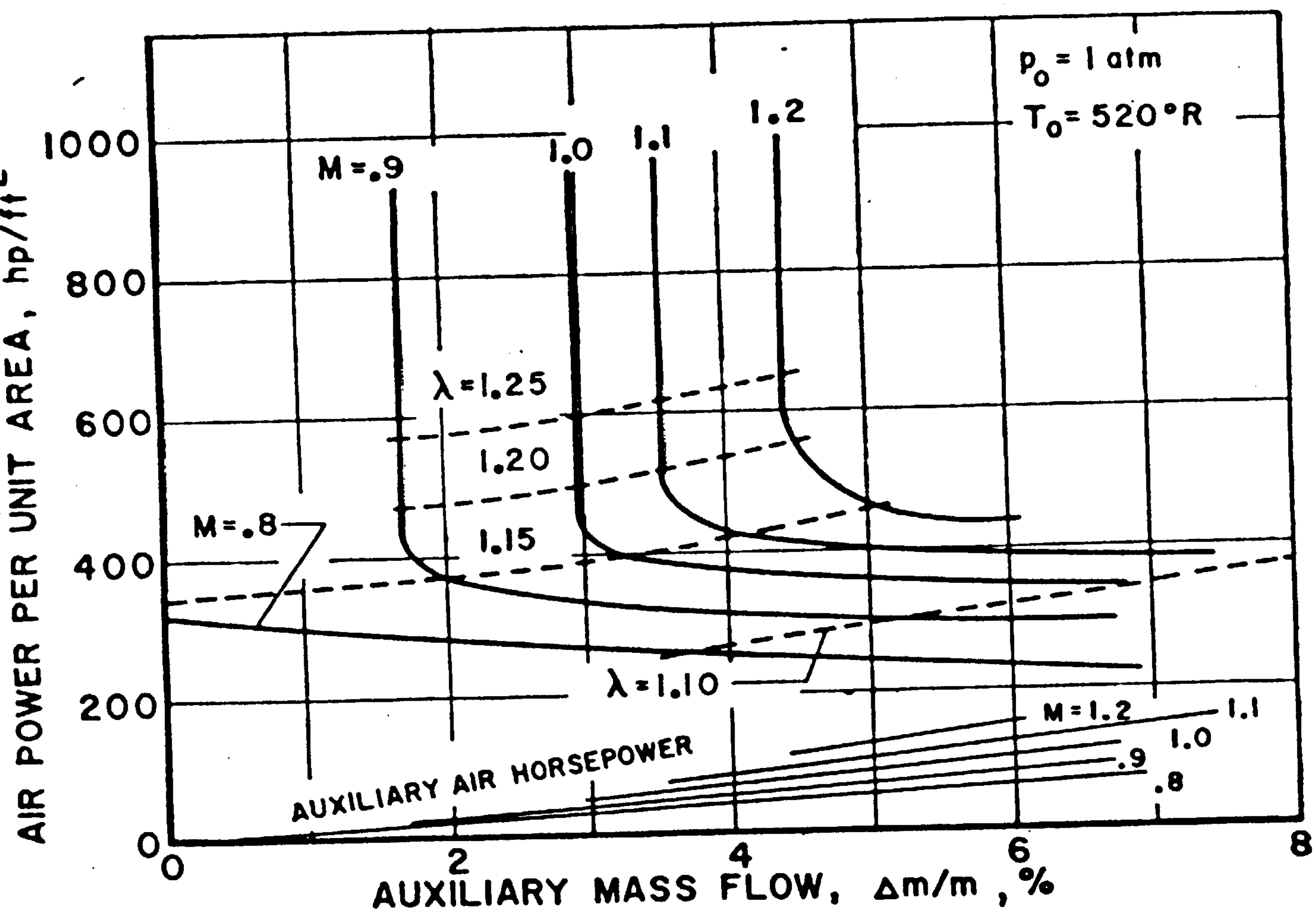


Fig. 14.16. *Power requirements and auxiliary mass flow of slotted test section for various Mach numbers (sixteen slots, 11 per cent open, diffuser flaps closed) (AEDC 1 ft transonic model tunnel[5]).*

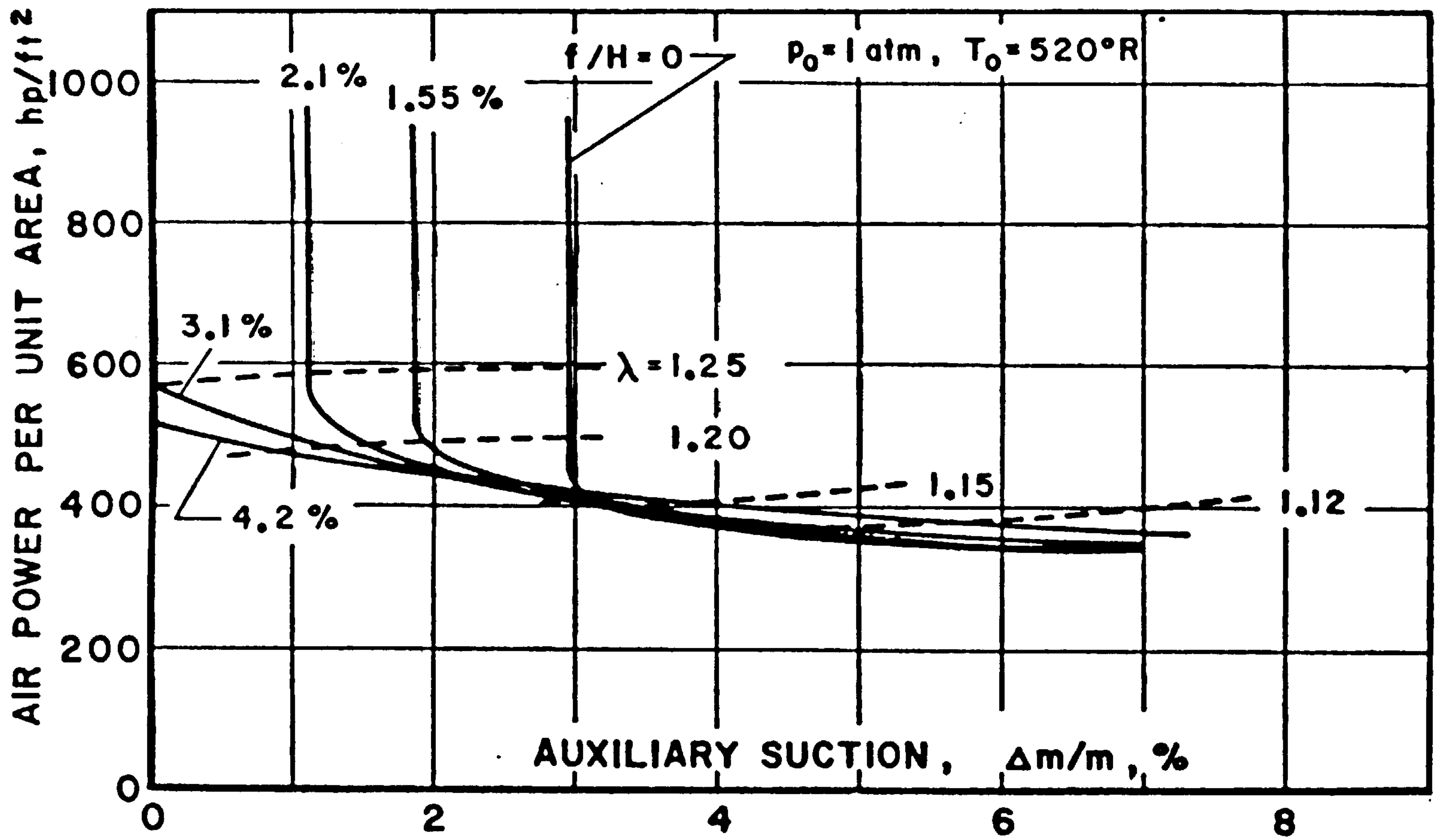


FIG. 14.17. *Influence of diffuser flap opening on power requirements of slotted test section at $M = 1.0$ (sixteen slots, 11 per cent open, parallel walls) (AEDC 1 ft transonic model tunnel*[5]*).*

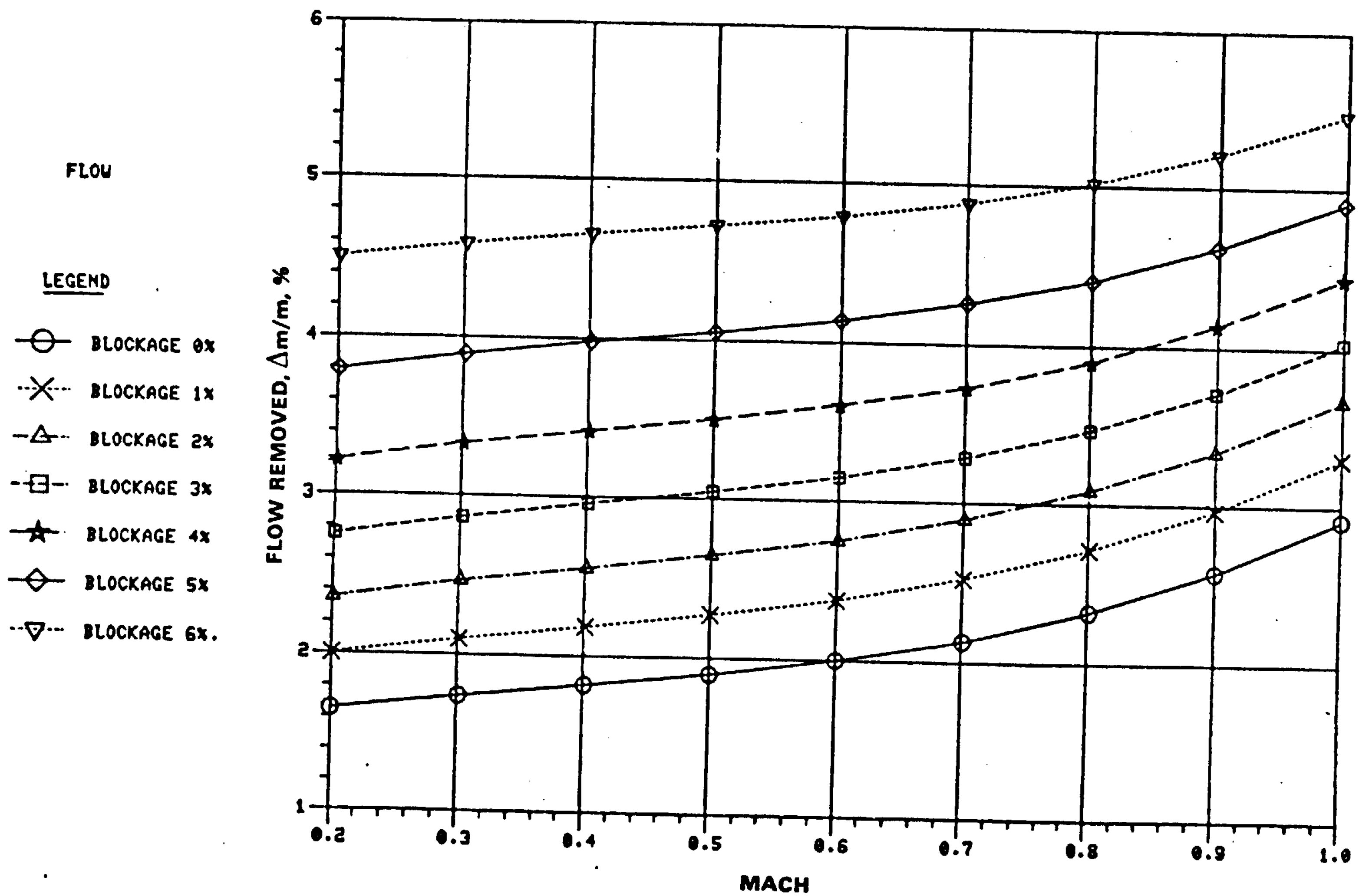


FIGURE 2. PLENUM FLOW REMOVAL REQUIREMENTS FOR AWT

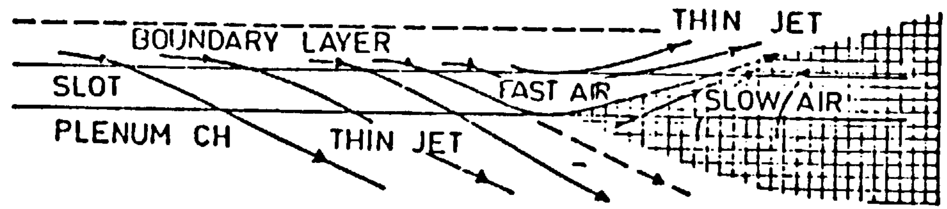
THE FIRST DIFFUSER ALGORITHM

Baseline Tunnel

$$B_t = B_{t,o} + \left(\frac{\Delta m}{m}\right), \%$$

PES Tunnel

$$B_t = B_{t,o}, \%$$



NYBERG'S SLOT FLOW MODEL

$$B_{t,o} = \left[1 - \frac{[A_{660}]e}{45{,}726.4} \right] 100, \%$$

$$[A_{660}]e = (233.68 - 2\delta^*_{ex})^2 (0.429705) + (236.24 - 2\delta^*_e)^2 (0.39889), \text{ in}^2$$

$$\delta^*_{ex} = 10.38275 \left[\frac{R_e}{\ell} \right]^{-1/5}, \text{ in}$$

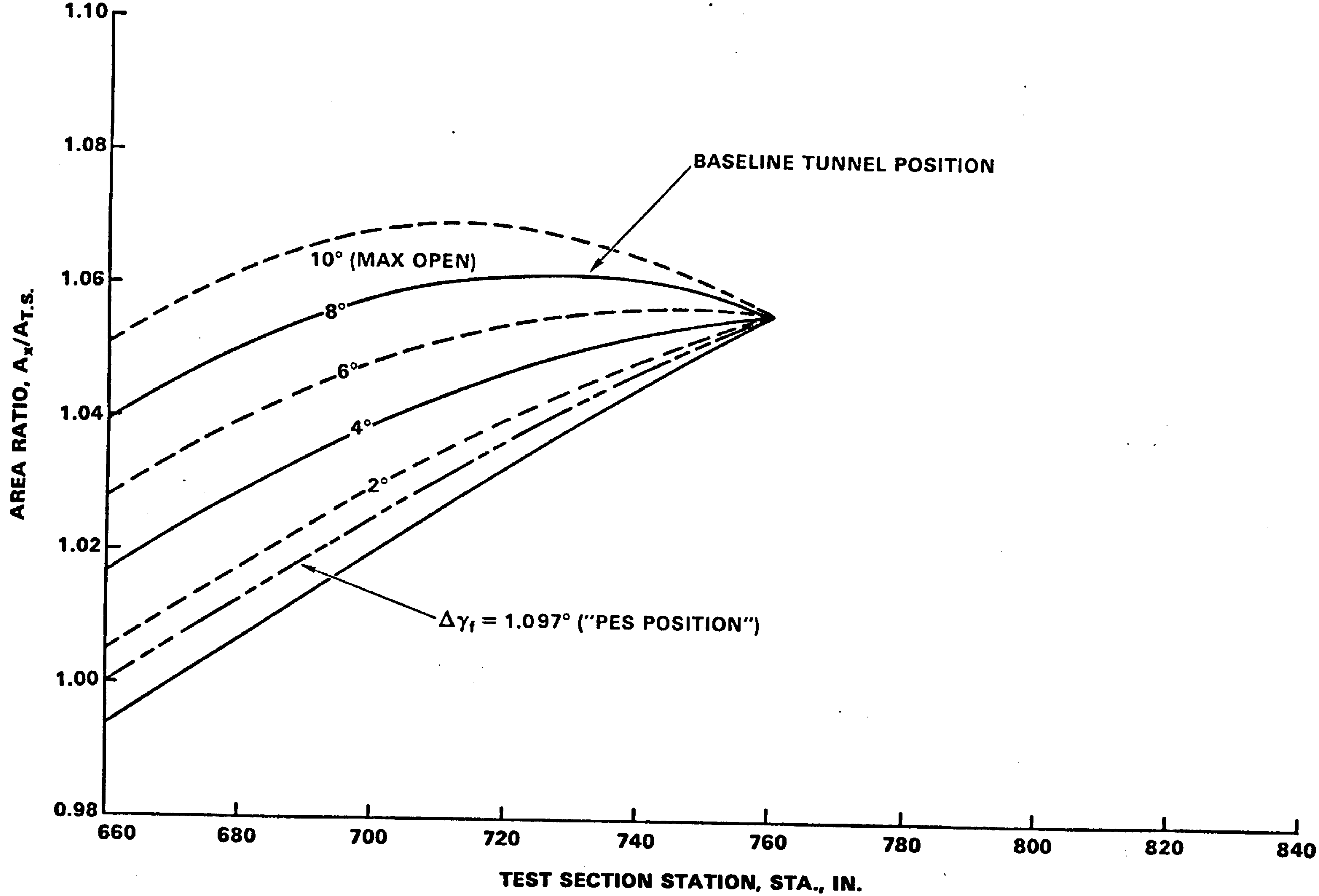


FIGURE 1. EFFECT OF EJECTOR FLAP OPENING ON DIFFUSER GEOMETRIC AREA DISTRIBUTION

CROSS-LEG DIFFUSER ALGORITHM & TEST LEG PRESSURE RATIO

- VARNER'S CODE FOR FIRST DIFFUSER DEFINES DIFFUSER EXIT BOUNDARY-LAYER BLOCKAGE

- THIS BLOCKAGE IS USED AS AN ARGUMENT FOR A CROSS-LEG DIFFUSER CALCULATION FURTHER ACCENTUATING THE INFLUENCE OF AN INDEPENDENT PES

- FOR CALCULATION AROUND THE MATCHED-ALTITUDE ENVELOPE (FIG. 5), THE PES-TUNNEL IS ALSO GIVEN THE ADVANTAGE THAT THE $\Delta m/m$ MASS FLOW DEFICIT REDUCES THE DIFFUSER ENTRANCE AND CORNER 1 MACH NUMBER (FIG. 6)

- THE RESULTING REDUCTION IN THE TEST LEG PRESSURE RATIO IS SHOWN IN (FIG. 7)

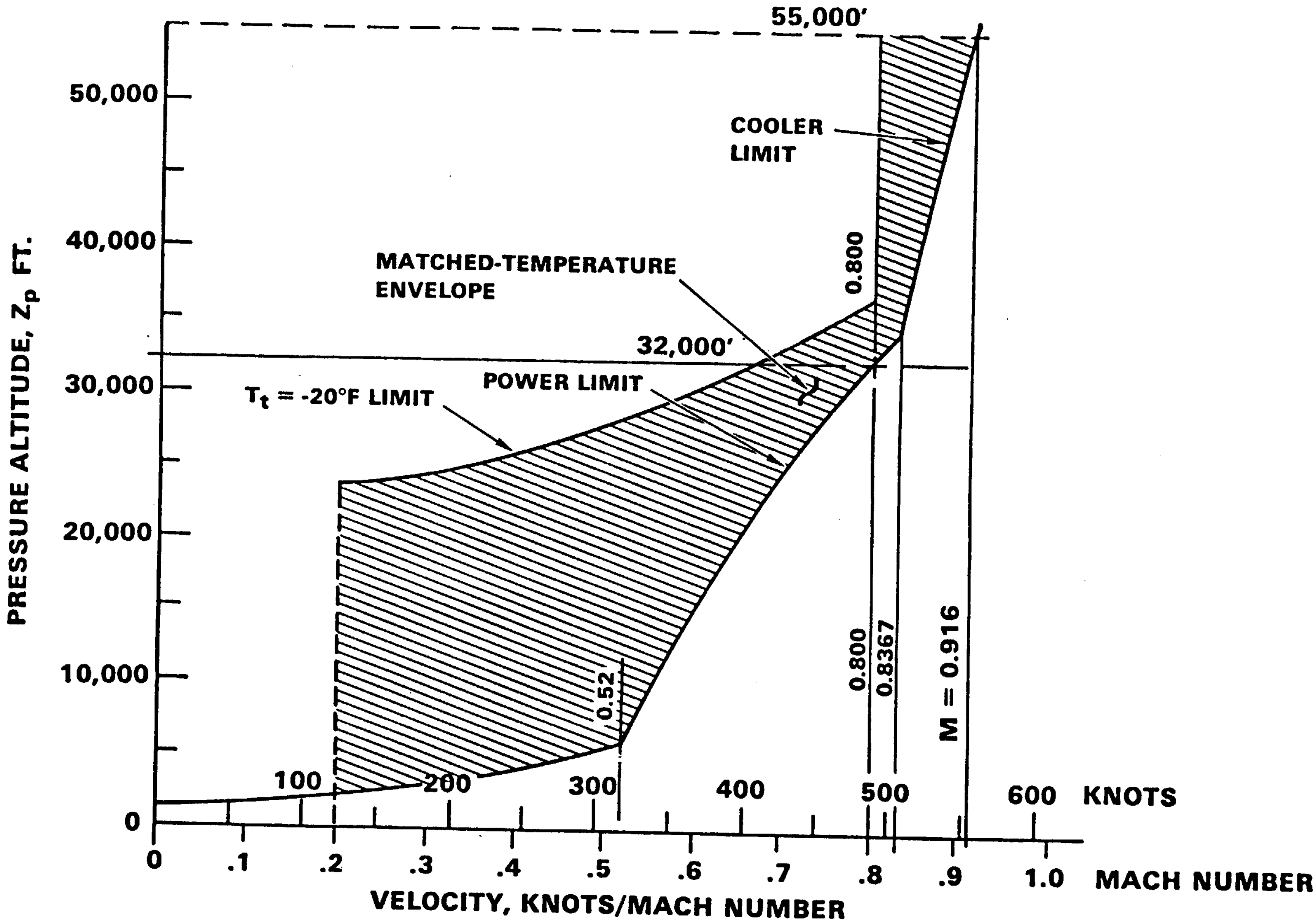


FIGURE 5. AWT PERFORMANCE 20' TEST SECTION

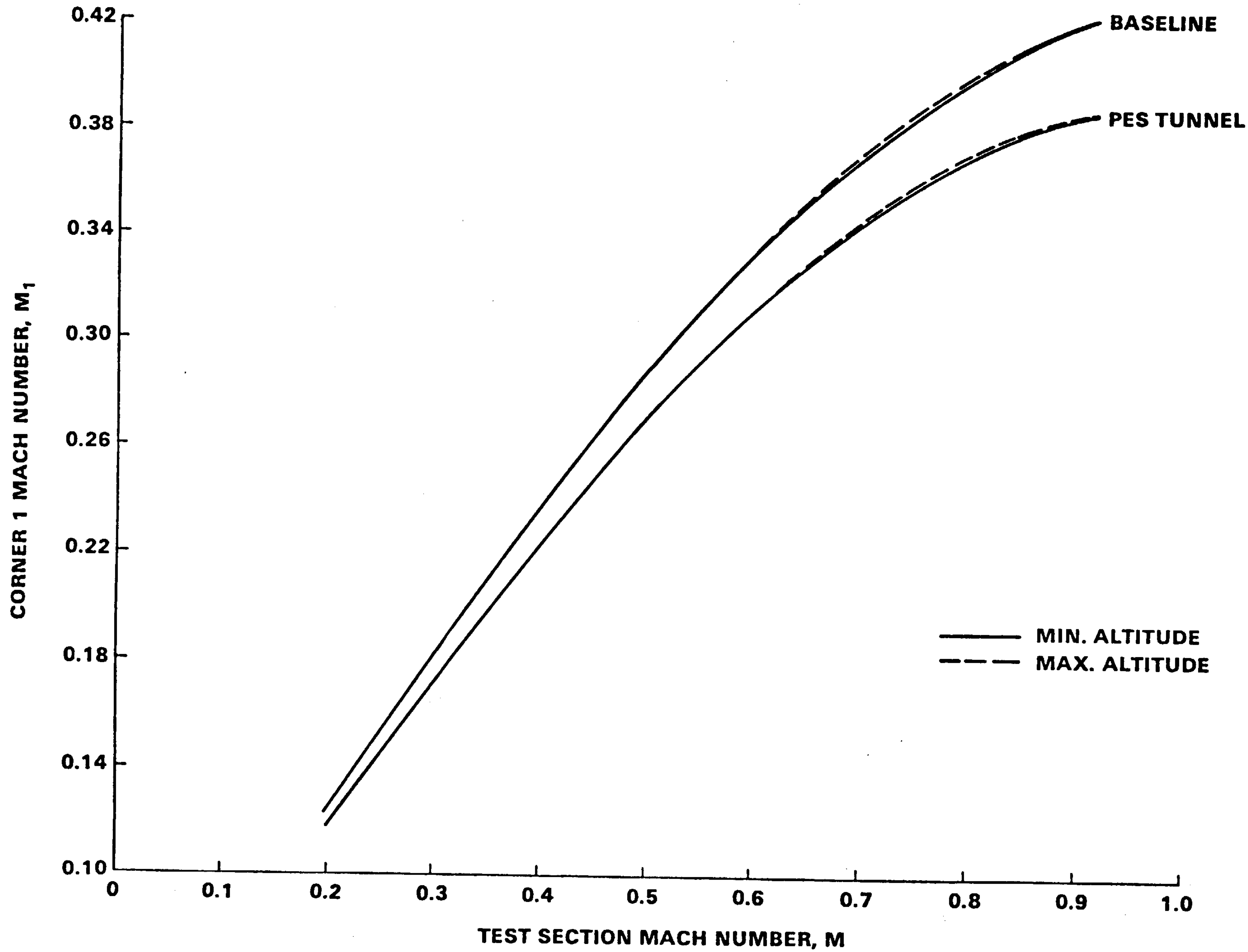


FIGURE 6. EFFECT OF PES SCHEME ON FIRST CORNER ENTRANCE MACH NUMBER, 6% MODEL CW

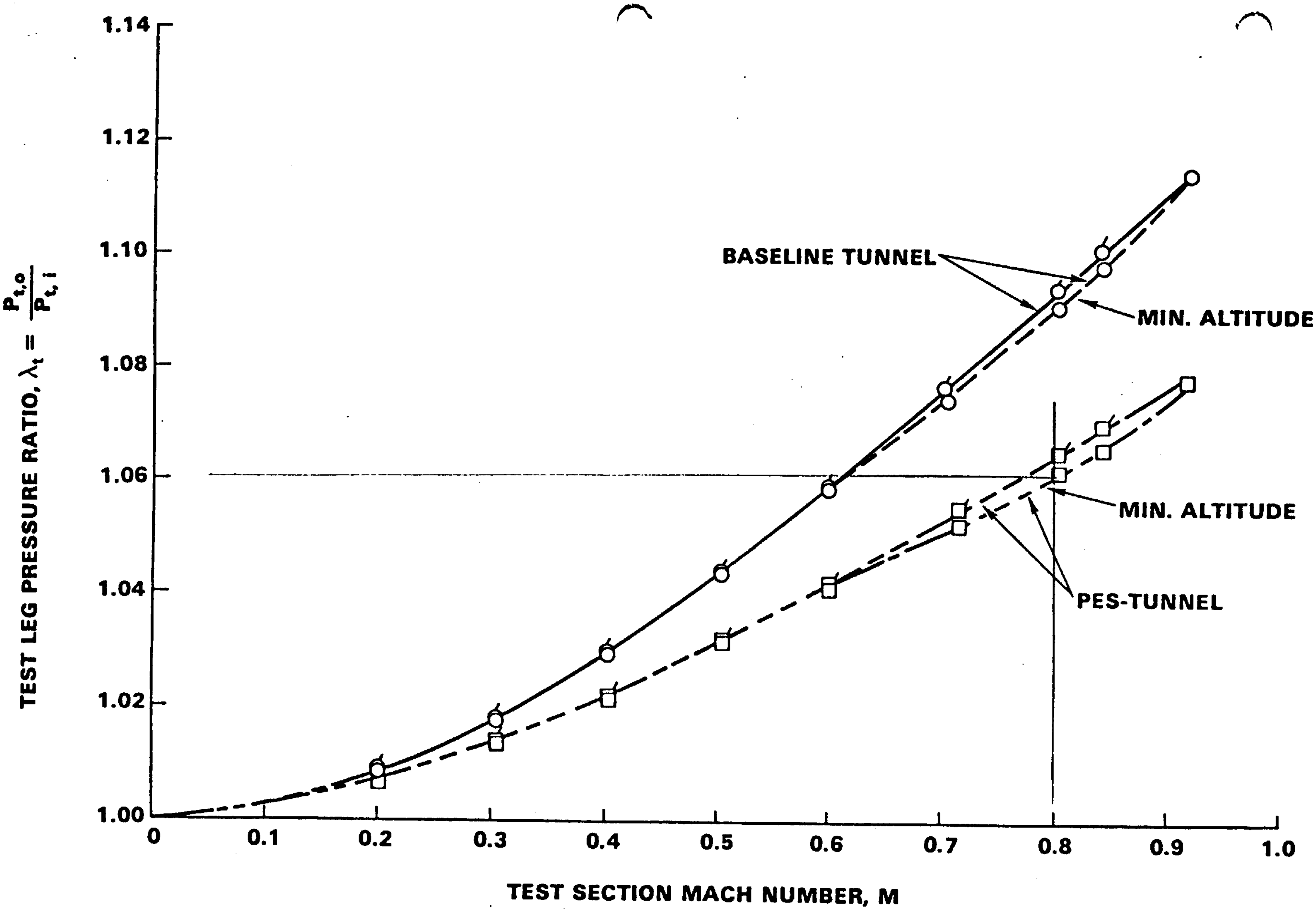
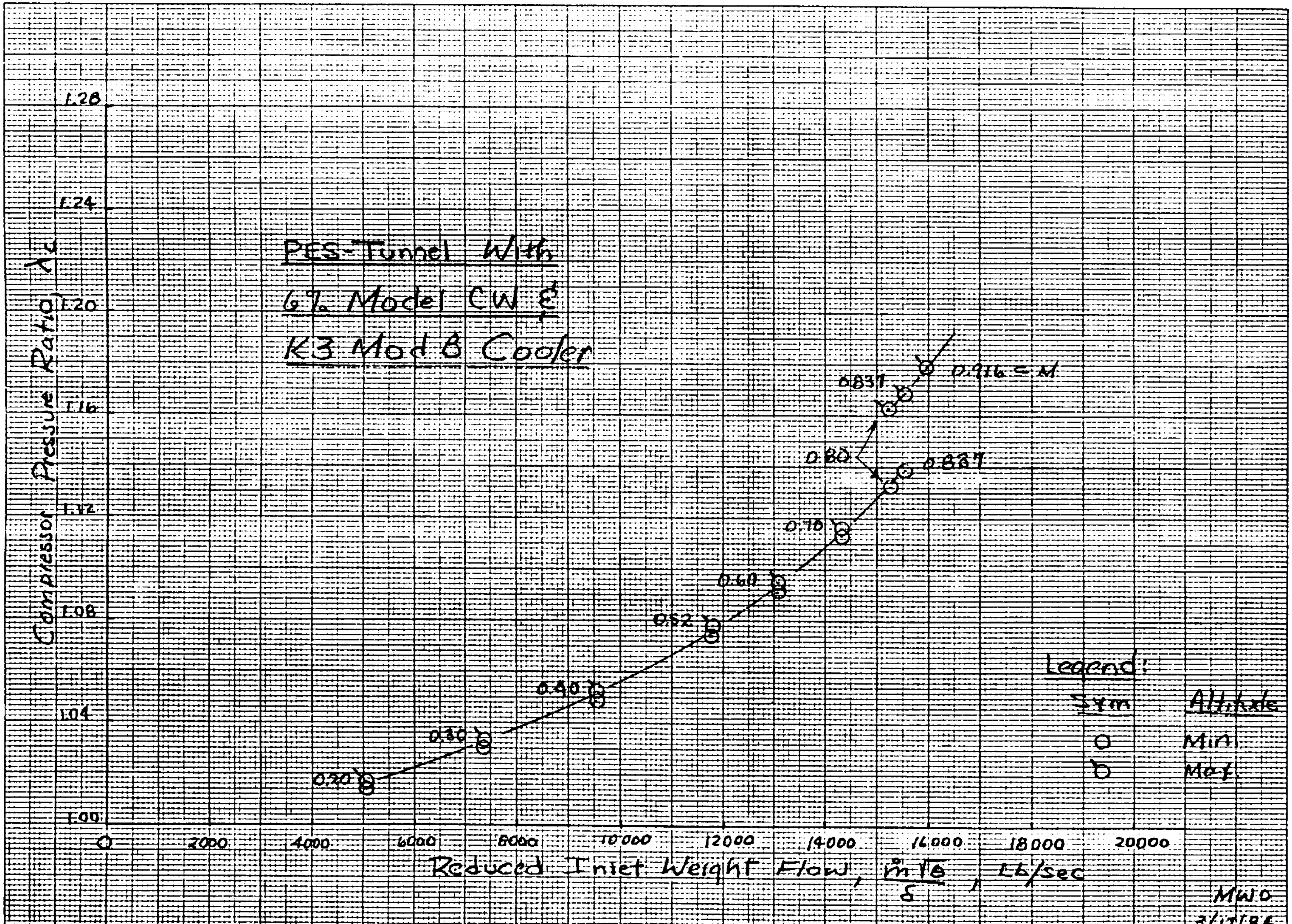
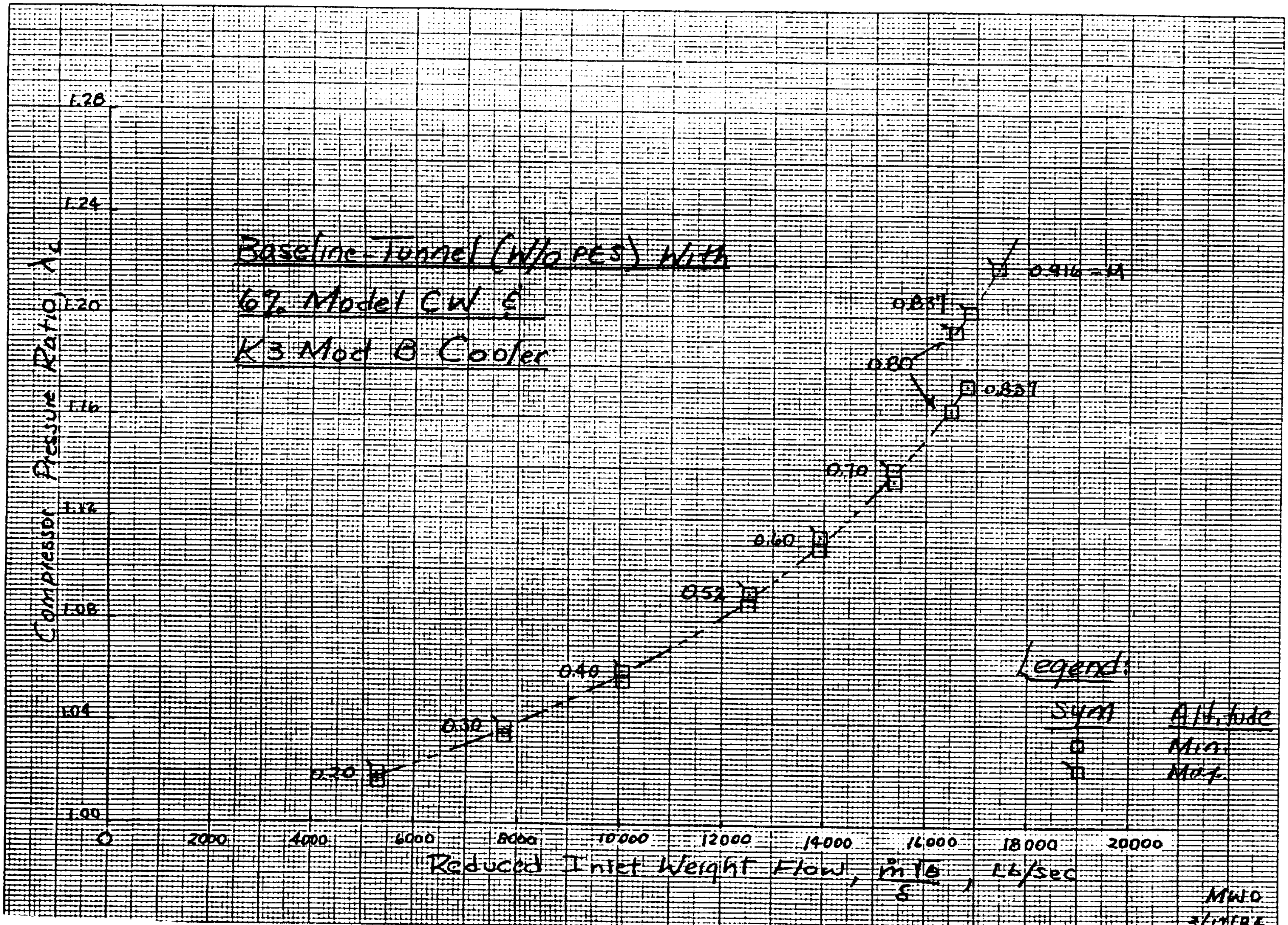
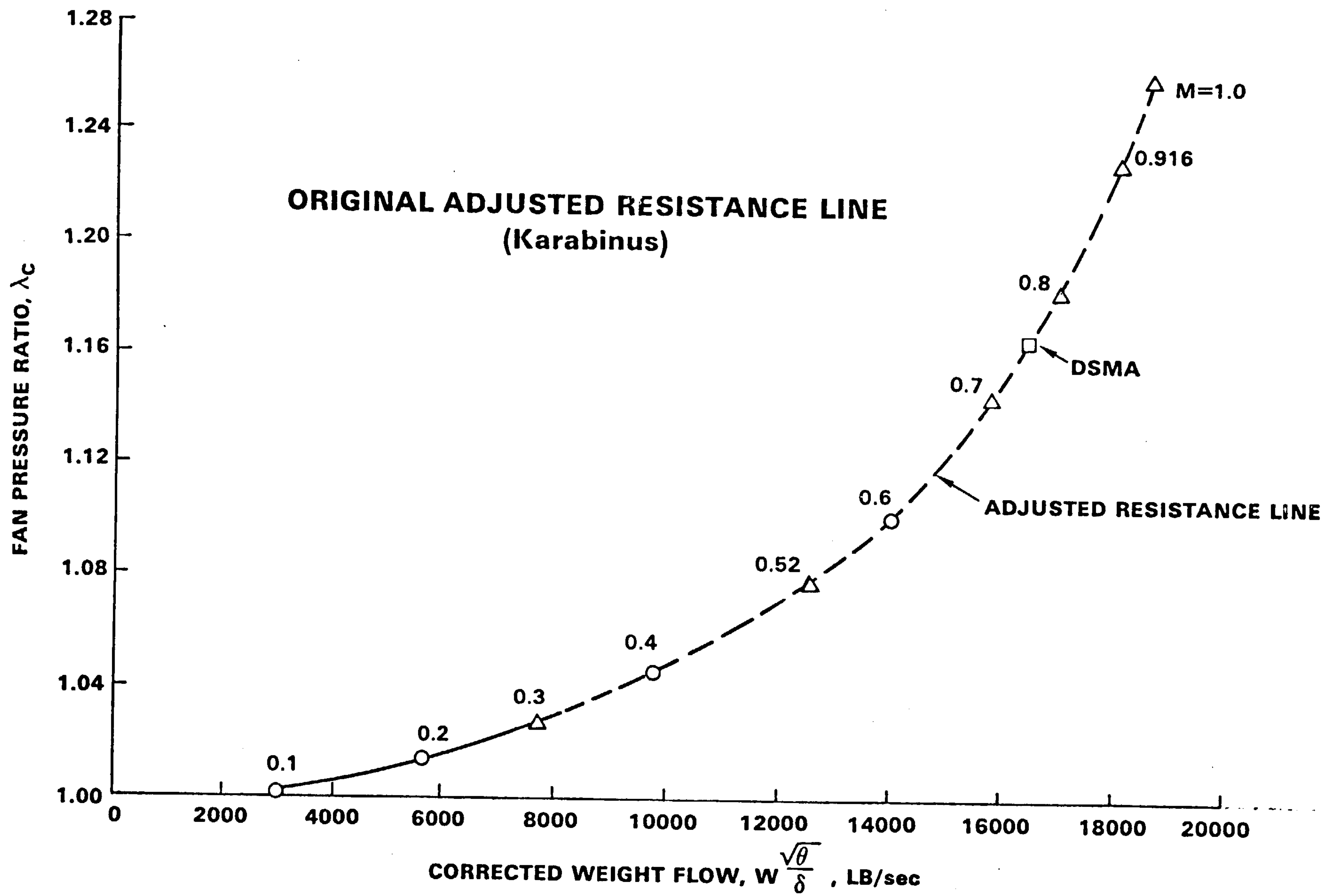


FIGURE 7. EFFECT OF PES SCHEME ON TEST LEG PRESSURE RATIO WITH 6% MODEL CW

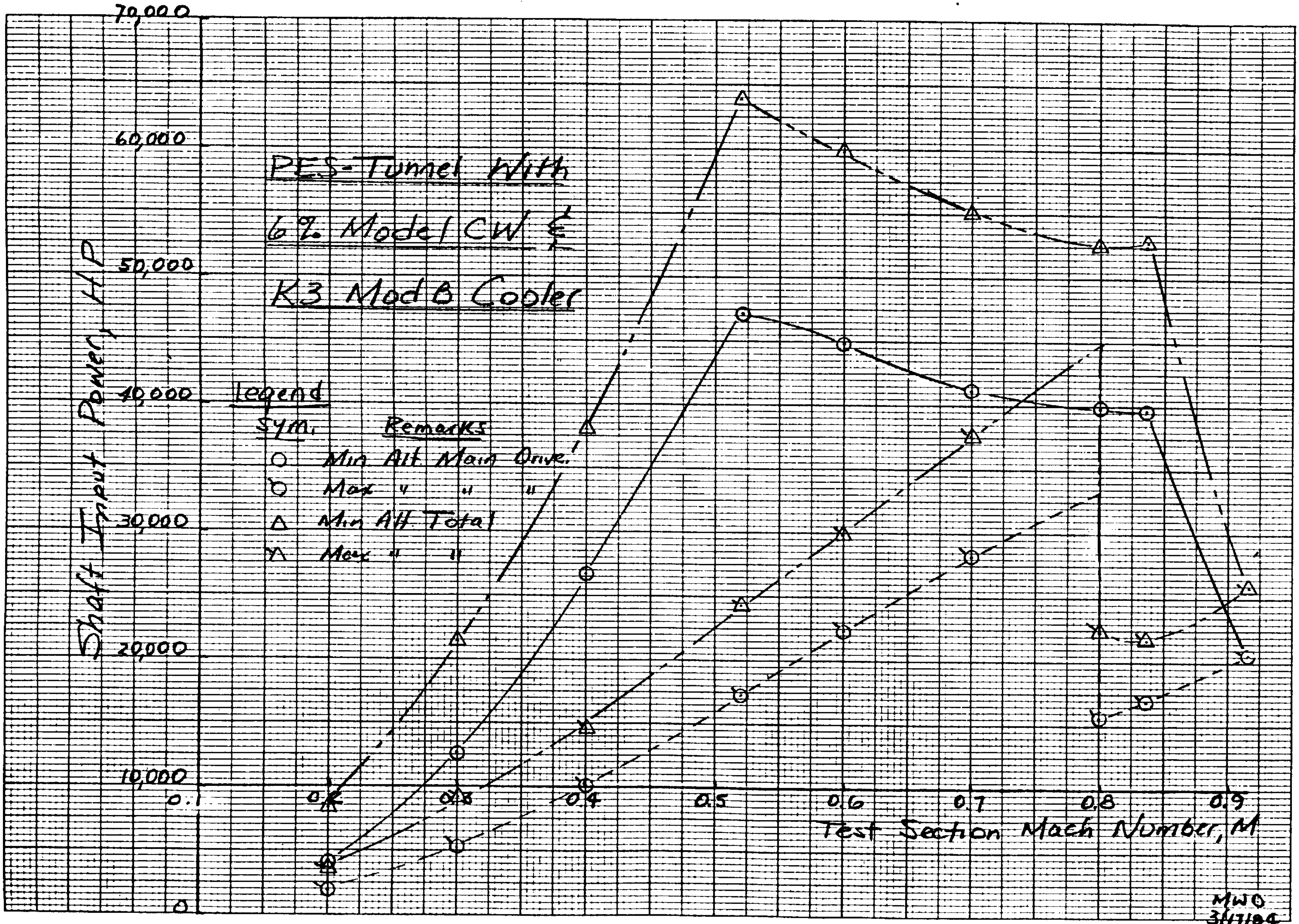


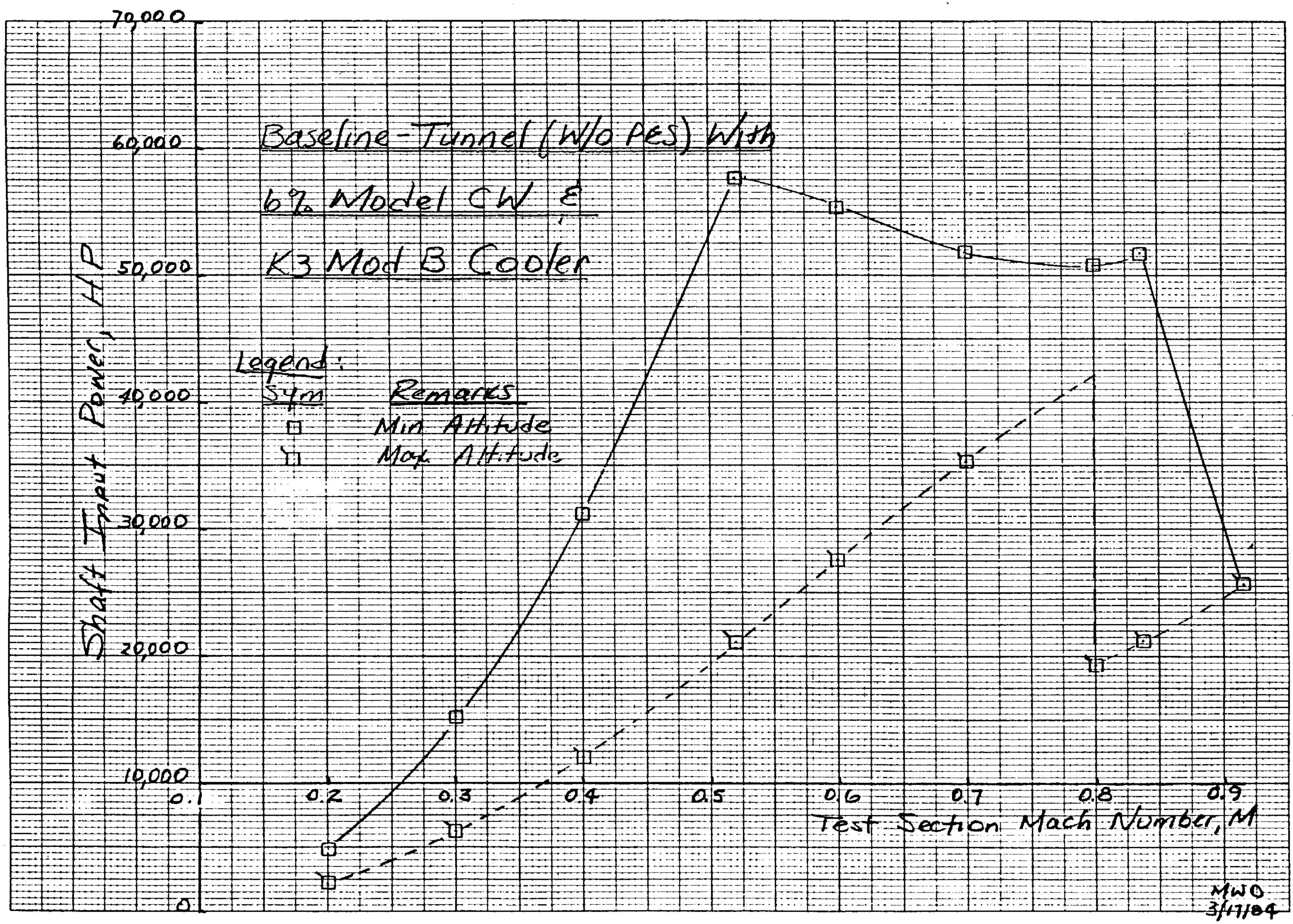
PES-Tunnel With
6% Model CW &
K3 Mod B Cooler
Compressor Pressure Ratio, λ_c
Reduced Inlet Weight Flow, $\frac{\dot{m}\sqrt{\theta}}{\delta}$, Lb/sec
1.00
1.04
1.08
1.12
1.16
1.20
1.24
1.28
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
0.20
0.30
0.40
0.52
0.60
0.70
0.80
0.837
0.837
0.916 = M
Legend:
Sym
Altitude
Min
Max
MWO
3/17/84

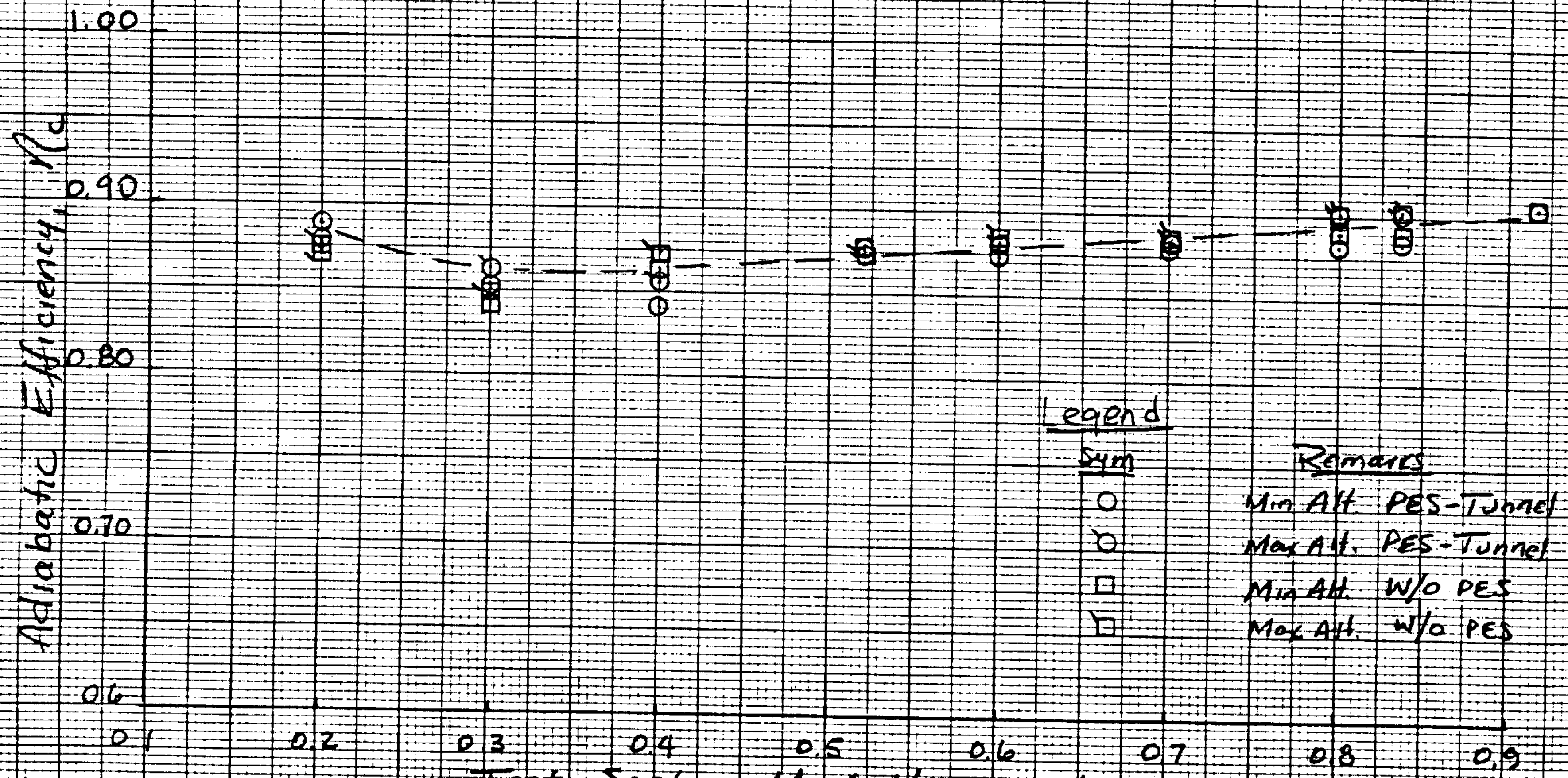

Baseline Tunnel (W/o PES) With
6% Model CW &
K3 Mod B Cooler
Compressor Pressure Ratio, λc
1.28
1.24
1.20
1.16
1.12
1.08
1.04
1.00
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Reduced Inlet Weight Flow, ṁ√θ/δ, Lb/sec
0.20
0.30
0.40
0.52
0.60
0.70
0.80
0.837
0.837
0.916 = M
Legend:
Sym
Altitude
Min.
Max.
MWO
3/17/84


ORIGINAL ADJUSTED RESISTANCE LINE
(Karabinus)
1.28
1.24
1.20
1.16
1.12
1.08
1.04
1.00
FAN PRESSURE RATIO, λ_C
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
CORRECTED WEIGHT FLOW, $W\frac{\sqrt{\theta}}{\delta}$, LB/sec
0.1
0.2
0.3
0.4
0.52
0.6
0.7
0.8
0.916
M=1.0
DSMA
ADJUSTED RESISTANCE LINE

K+E 10 X 10 TO 1/2 INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1322



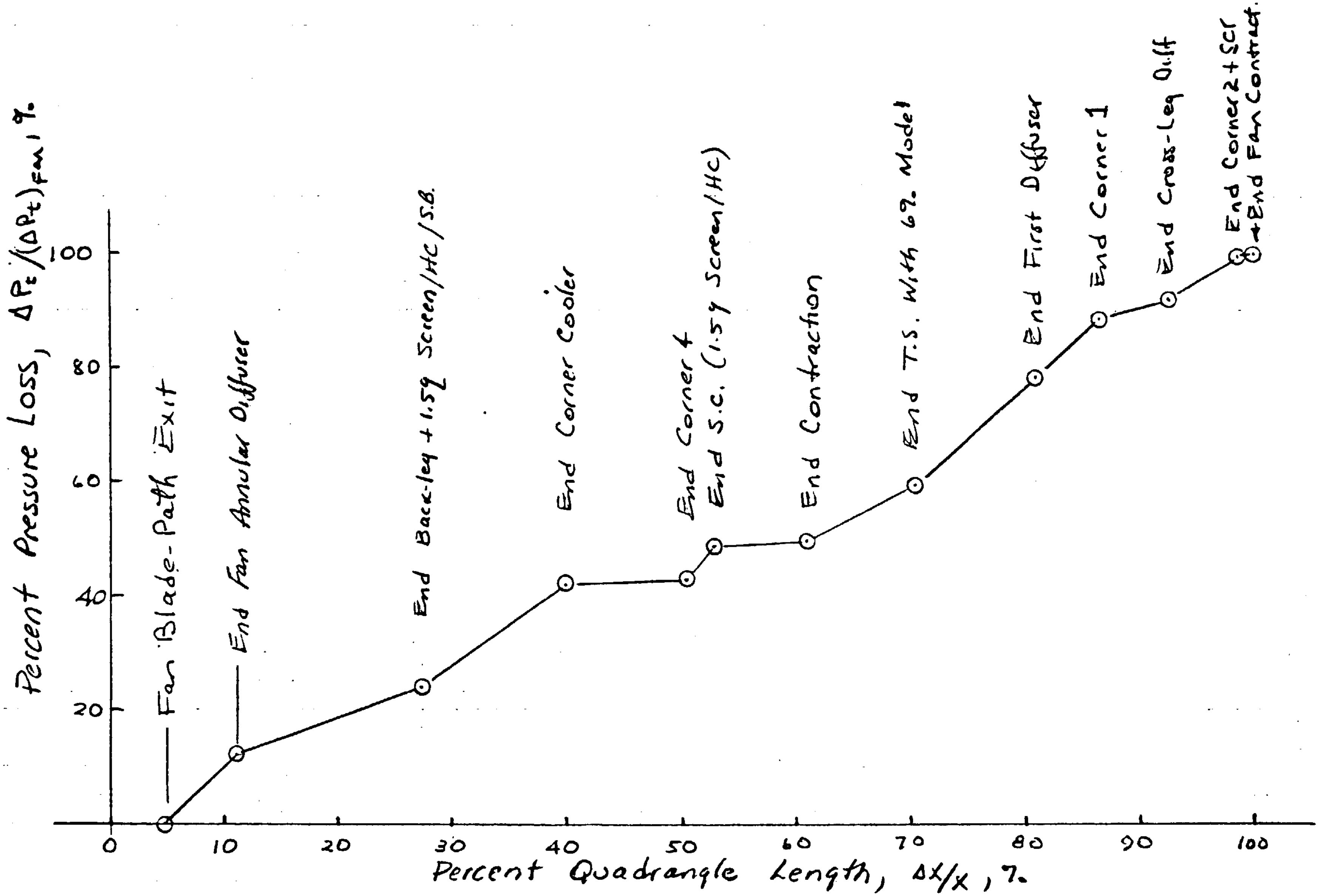

Baseline-Tunnel (W/o PES) With
6% Model CW &
K3 Mod B Cooler
Legend:
Sym Remarks
Min Altitude
Max Altitude
Shaft Input Power, HP
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Test Section Mach Number, M
MWO
3/17/84



Adiabatic Efficiency Locii For Two Tunnels

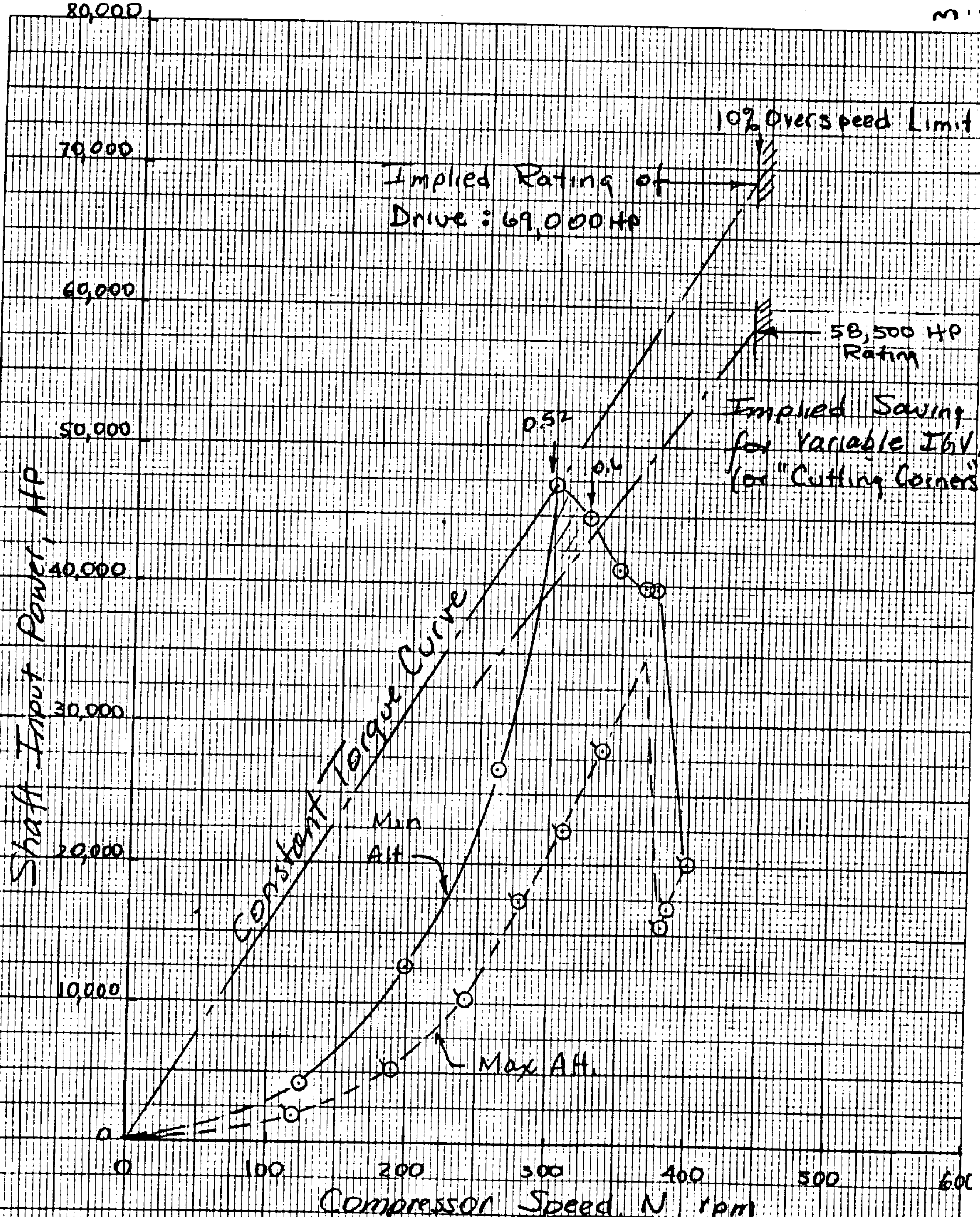
(Main Drive Compressor Match)

MWD
3/17/84



PES-Tunnel, M=0.8, Z_p = 32,000 ft
Ducting Pressure Loss Build-Up. With K3 Mod B Cooler
& Alternate ℄ Scoop With Tip

MWD
3/19/84



The Power-Speed Envelope PES-Tunnel

(Motor/Compressor Match)

MWD
3/17/84

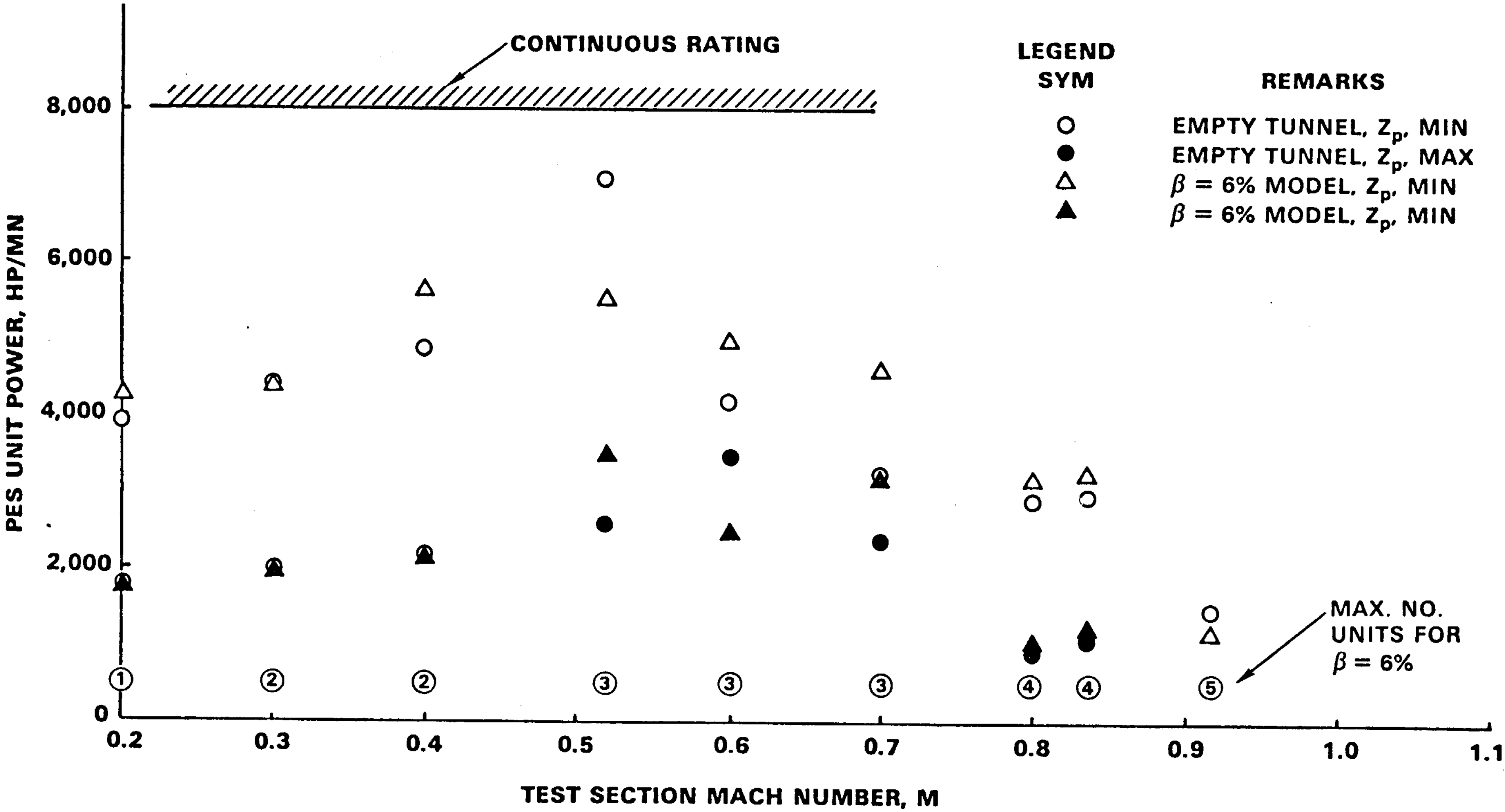


FIGURE 3. AWT-PES UNIT COMPRESSOR POWER FOR VARIOUS TEST CONDITIONS, DRY AIR W/O INLET HEATING

216

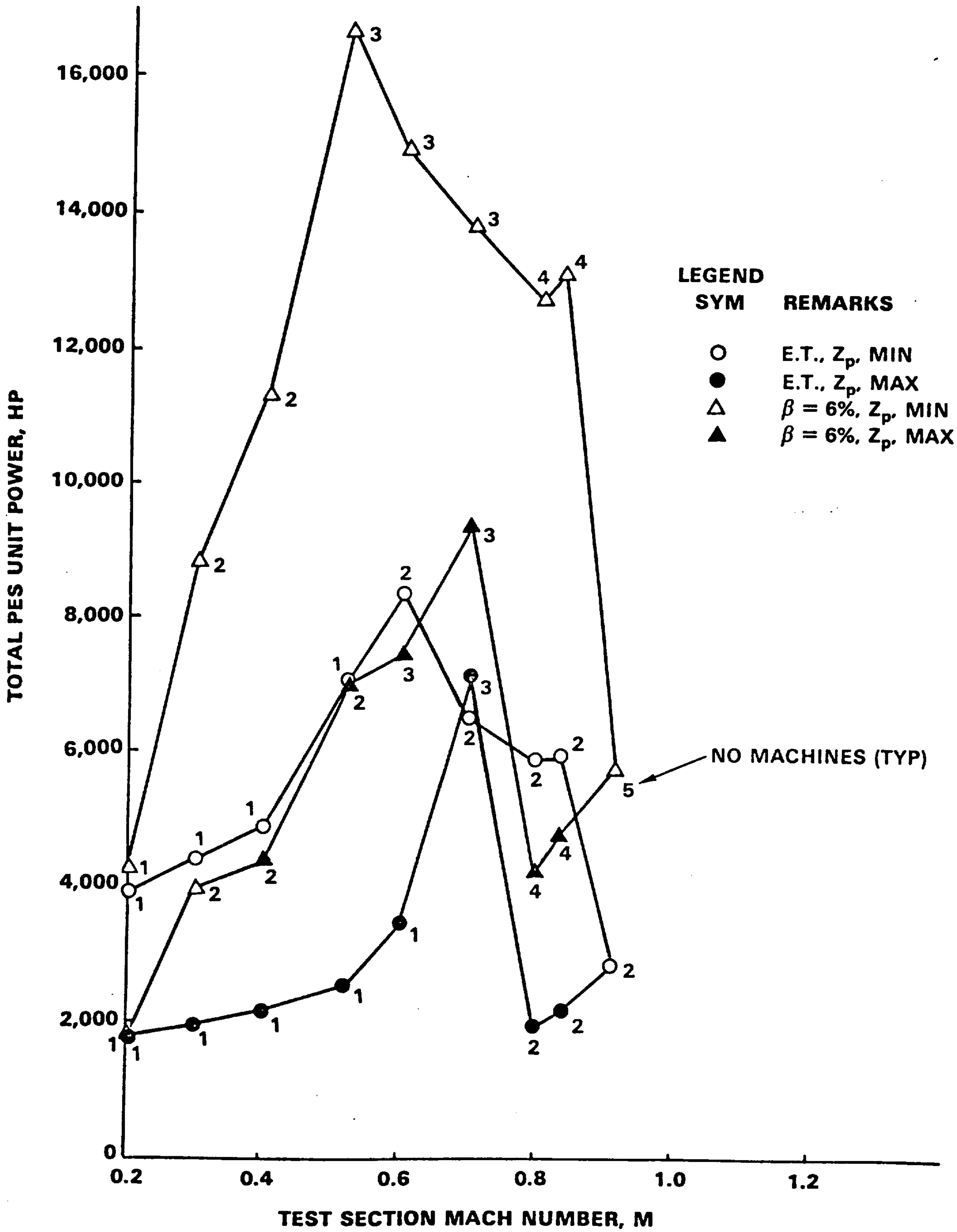
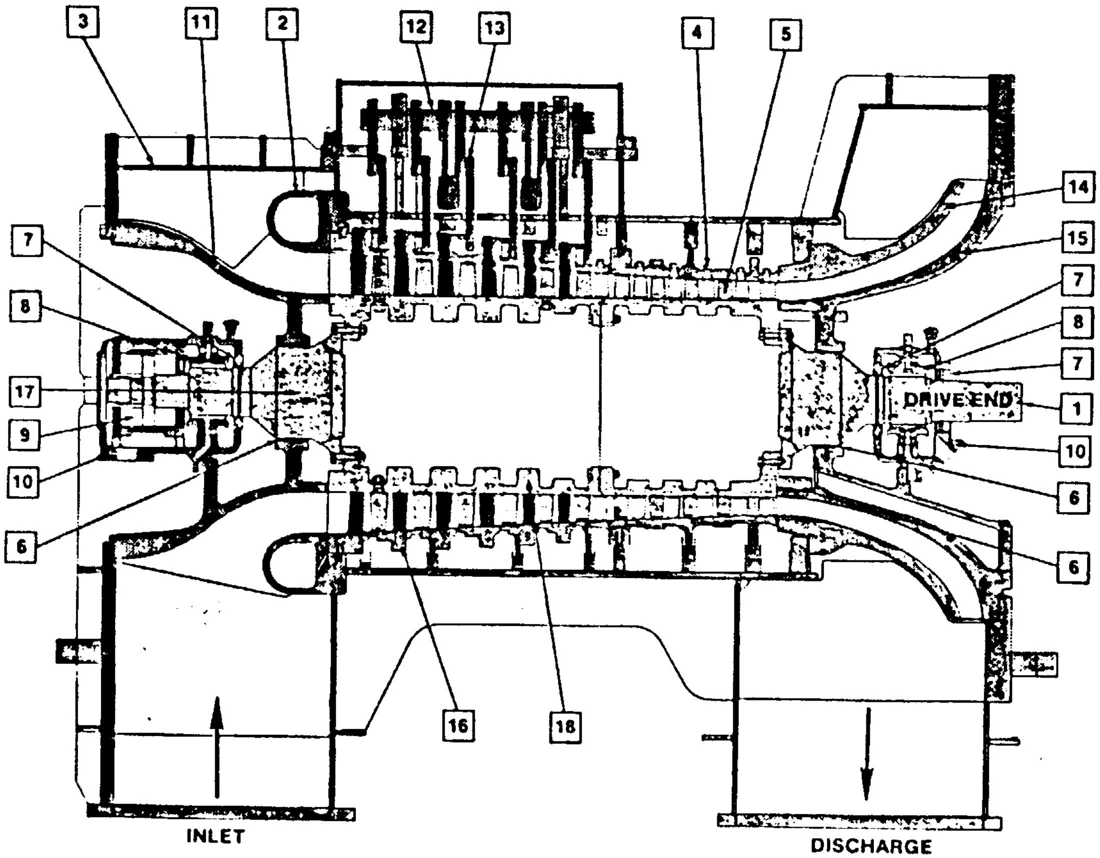


FIGURE 4. AWT-PES TOTAL COMPRESSOR POWER FOR VARIOUS TEST CONDITIONS, DRY AIR

construction features



1 Compressor Rotor Assembly
2 Fairing Ring
3 Casing
4 Stator Blading
5 Rotor Blading
6 Shaft Sealing "J-Strips"
7 Oil Baffle
8 Load Bearing
9 Thrust Bearing
10 Bearing Housing
11 Inlet End Bell
12 Operating Shaft
13 Movable Guide Vane Mech.
14 Diffuser
15 Disch. End Bell
16 Stator
17 Rotor Stub
18 Rotor Body

FIGURE 9. CONSTRUCTION FEATURES OF AN ALLIS-CHAMBERS 1410

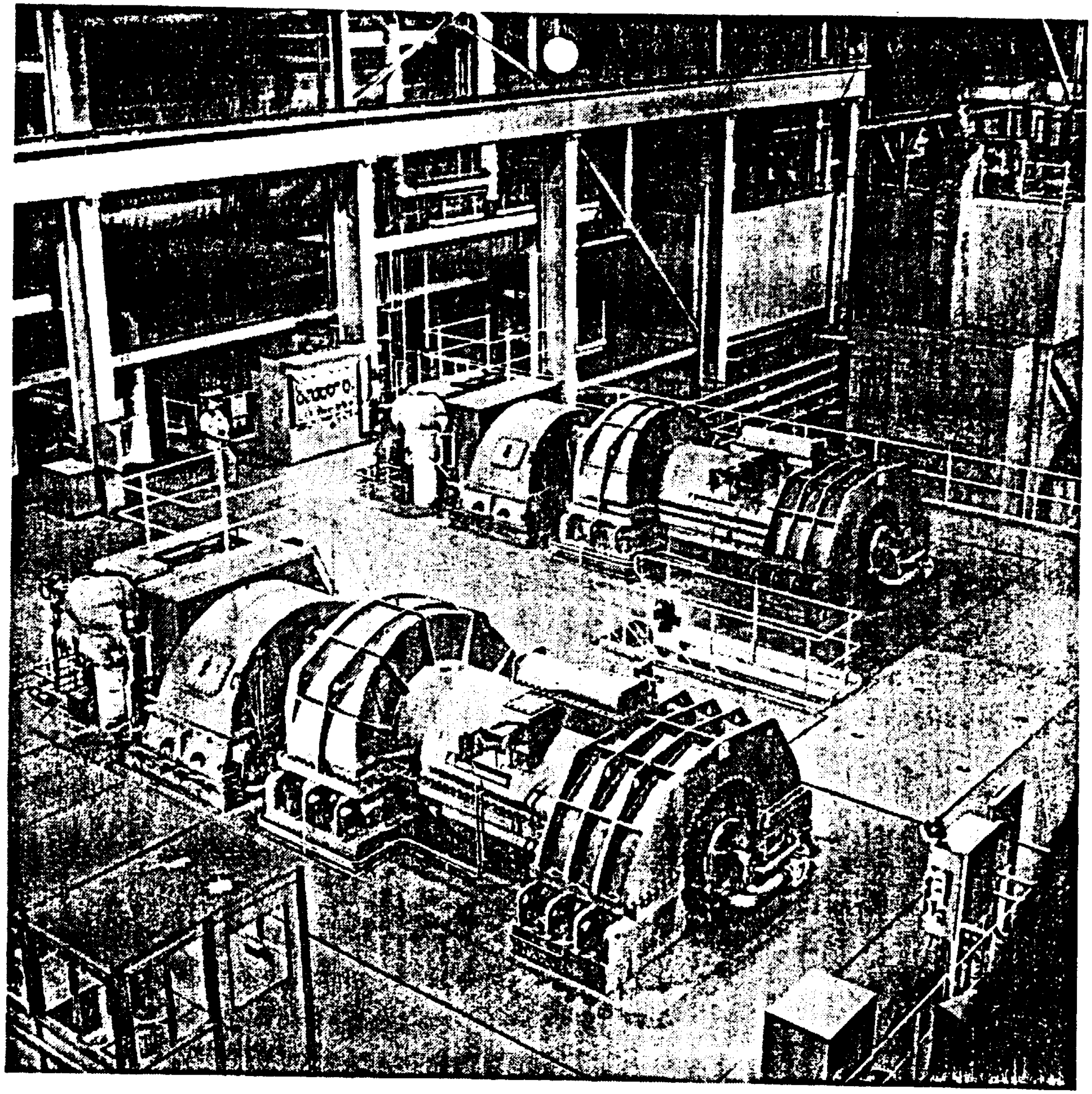


FIGURE 10. THE MAINTENANCE ADVANTAGE FOR A MEZZANINE LAYOUT OF AC 1410 MACHINES

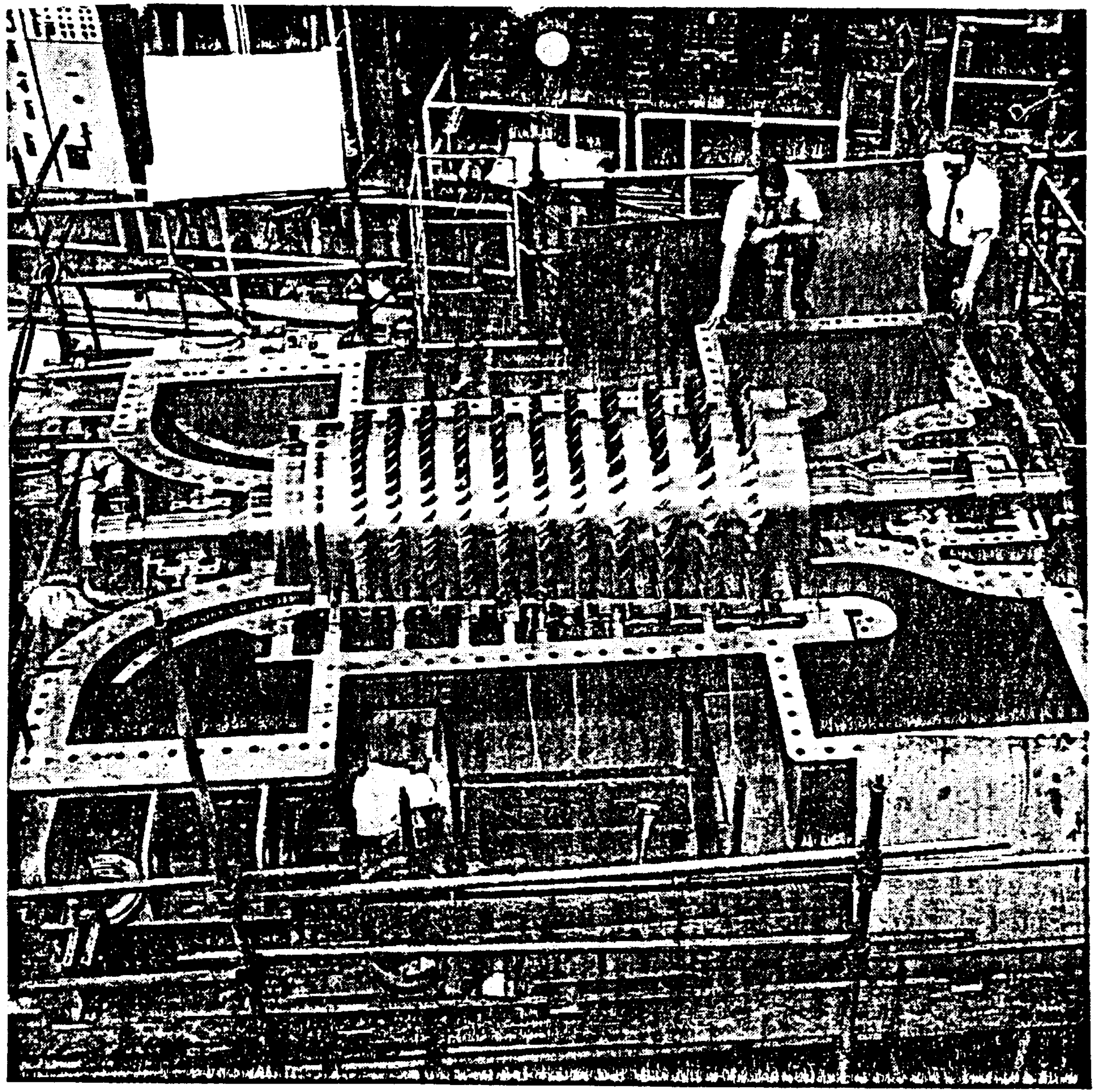
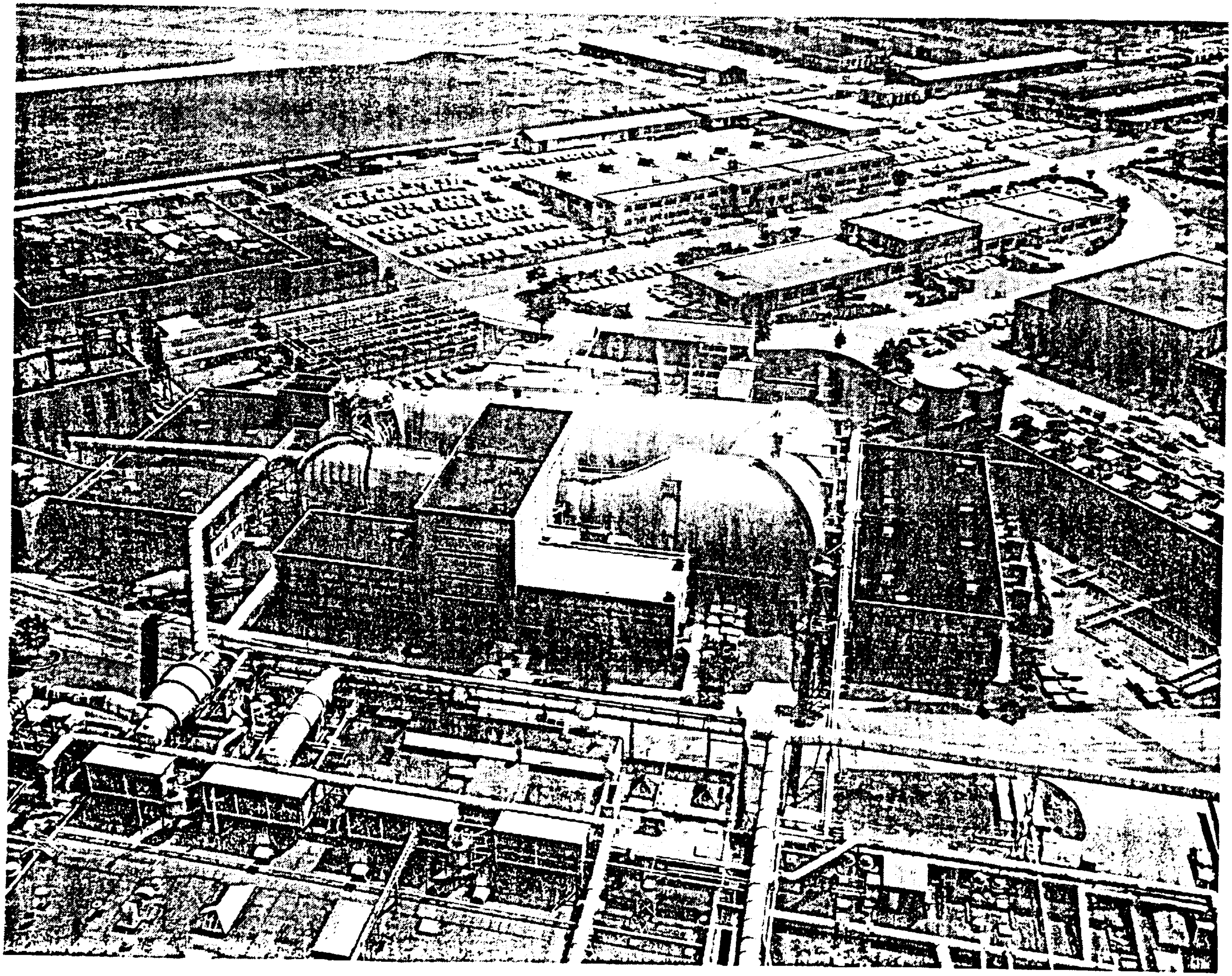
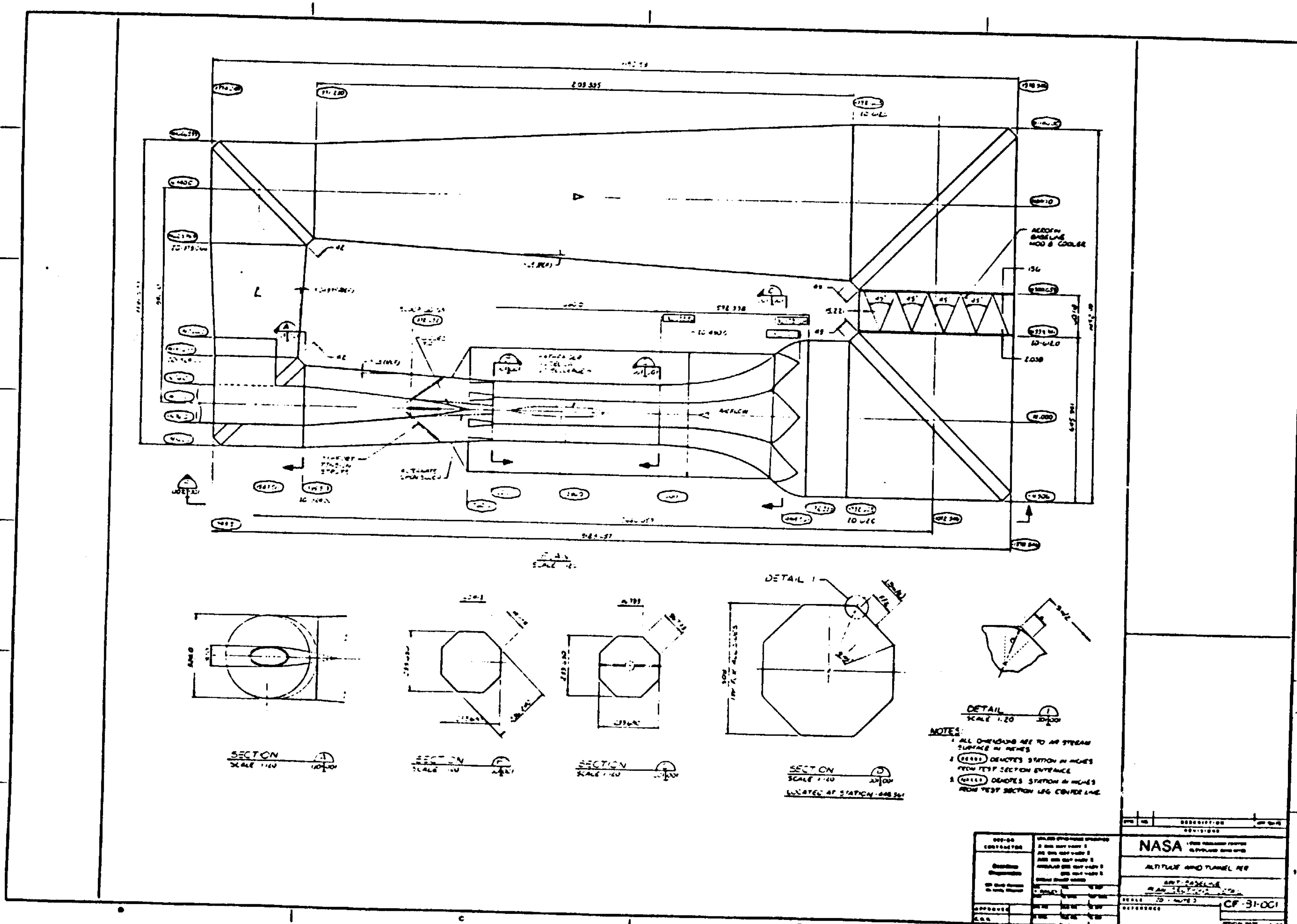


FIGURE 11. THE MAINTENANCE ADVANTAGE FOR A CASING WITH A HORIZONTAL SPLIT

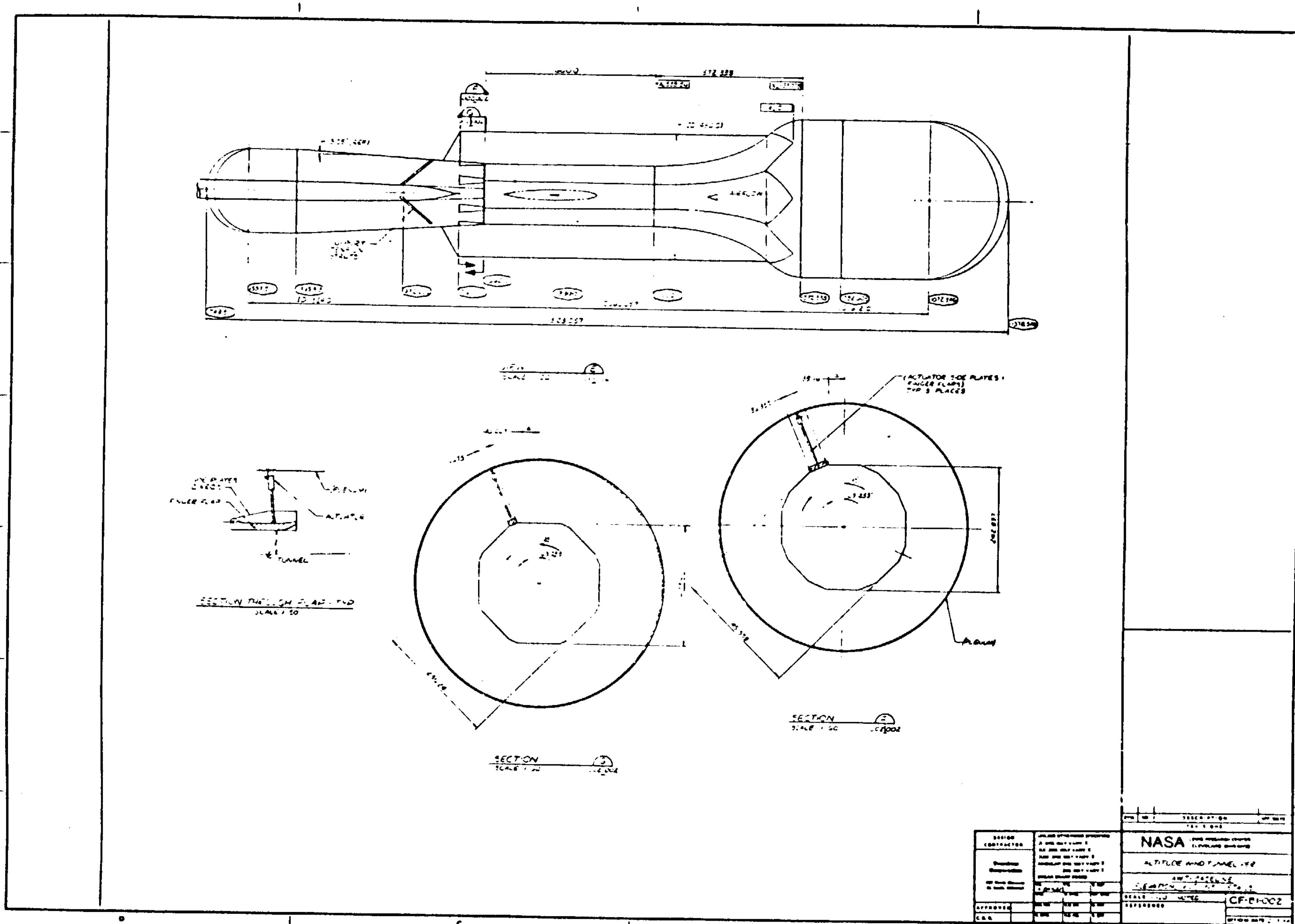
AIRLINE DEFINITION

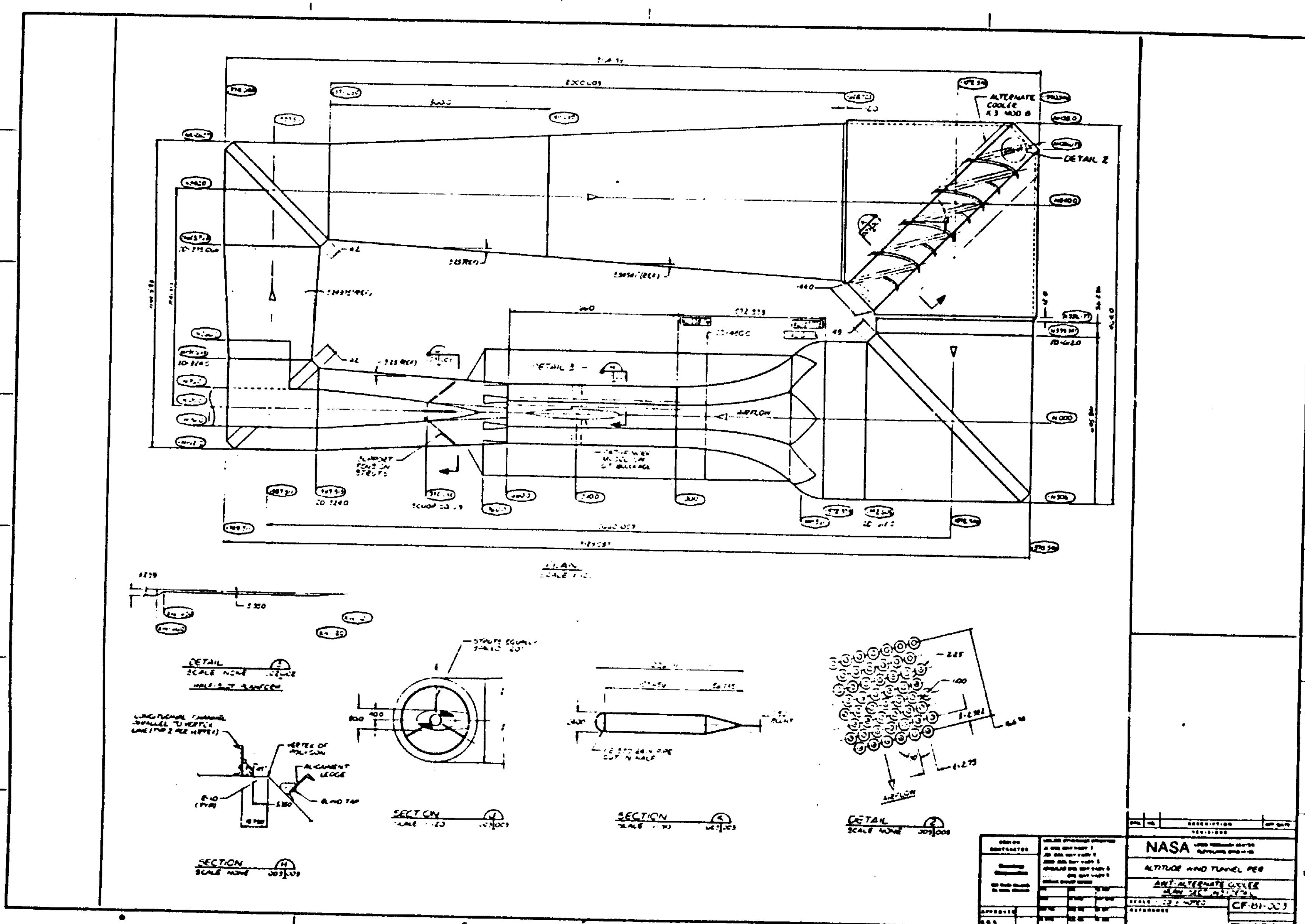
- BASELINE SCAVENGING SCOOP
- AEROFIN BASELINE MOD B COOLER
- K3, MOD B COOLER





DETAIL 1
SECTION
SECTION
SECTION
SECTION
DETAIL
SCALE 1:20
NOTES:
1 ALL DIMENSIONS ARE TO AIR STREAM SURFACE IN INCHES
2 DENOTES STATION IN INCHES FROM TEST SECTION ENTRANCE
3 DENOTES STATION IN INCHES FROM TEST SECTION LEG CENTER LINE
NASA
ALTITUDE WIND TUNNEL
CF-31-001


AIRFLOW
SECTION THROUGH FLAP - TYP
SECTION
SECTION
NASA
ALTITUDE WIND TUNNEL
CF-E1-002
DESIGN CONTRACTOR
APPROVED
SCALE
REFERENCE


ALTERNATE COOLER
DETAIL 2
AIRFLOW
DETAIL 3
PLAN
DETAIL
SECTION
SECTION
SECTION
DETAIL
VERTEX OF POLYGON
ALIGNMENT LEDGE
BLIND TAP
NASA
ALTITUDE WIND TUNNEL PER

CONTRACTION GEOMETRY AND CODE ANALYSIS

TWO CONTRACTIONS WERE DESIGNED FOR AWT USING THE "MODIFIED SINE-LAW" APPROACH WITH BOUNDARY CONDITIONS, AS FOLLOWS:

- MOD A WAS CHOSEN TO BE 9.3786 FT. SHORTER THAN THE ORIGINAL AWT CONTRACTION
- MOD B WAS CHOSEN TO BE 15.0074 FT. SHORTER THAN THE ORIGINAL AWT CONTRACTION
- VNAP CODE RESULTS

MOD A. (9.3786 FT. SHORTER THAN ORIGINAL)

LAST HONEYCOMB/SCREEN, $\Delta X/D_{H,I}$

	0.25		0.175		0.100	
	VEL fps.	% DEV.	VEL fps.	% DEV.	VEL fps.	% DEV.
WALL	793.97	+1.11	796.67	+1.24	796.37	+1.44
℄	780.27	-0.53	781.61	-0.68	778.93	-0.78
AVG.	785.25		786.95		785.07	
TOTAL DEV		1.74		1.92		2.22

MOD B. (15.0074 FT. SHORTER THAN ORIGINAL)

LAST HONEYCOMB/SCREEN, $\Delta X/D_{H,i}$

	0.25		0.174		0.100	
	VEL fps.	% DEV.	VEL fps.	% DEV.	VEL fps.	% DEV.
WALL	800.58	+1.34	788.10	+0.55	794.95	+1.25
℄	791.94	+0.25	773.76	-1.18	779.03	-0.78
℄ + 30	779.94	-1.27				
AVG.	789.99		782.96		795.15	
TOTAL DEV		2.61		1.84		2.03

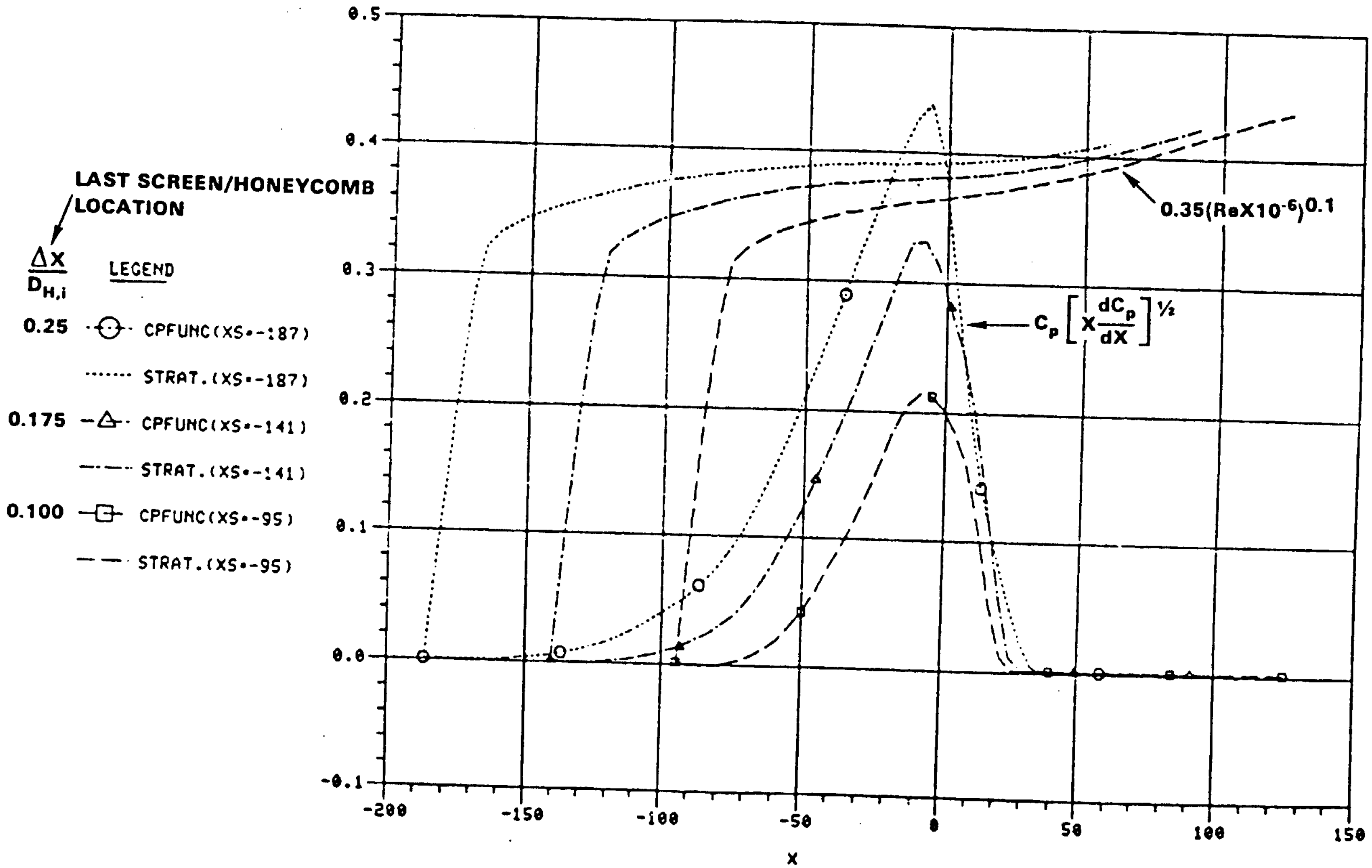


FIGURE 1. CHECK OF MOD A CONTRACTION FOR INLET FLOW SEPARATION (CONTRACTION 9.3786 FT. SHORTER)

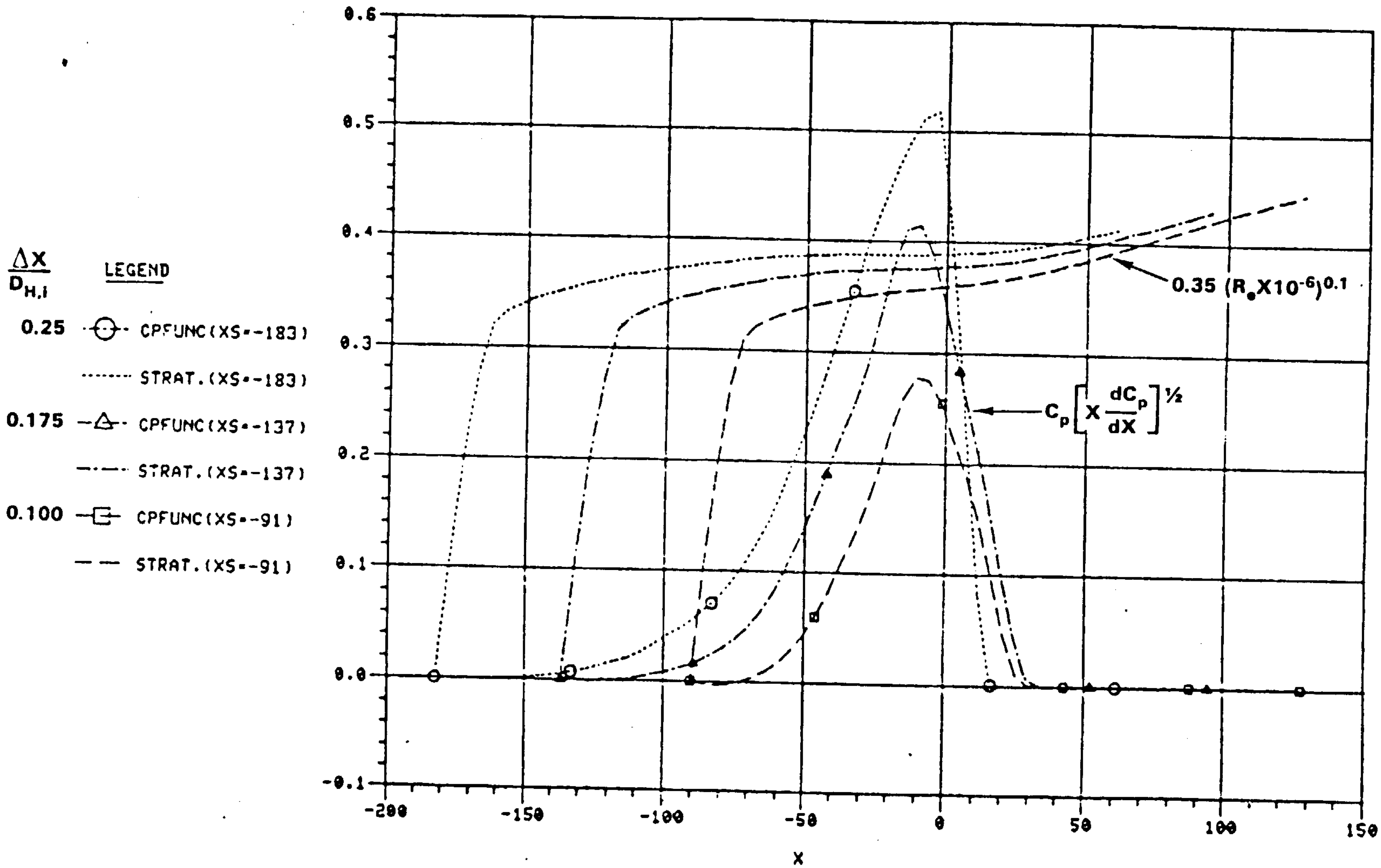


FIGURE 2. CHECK OF MOD B CONTRACTION FOR INLET FLOW SEPARATION (CONTRACTION 15.0074 FT. SHORTER)

CONTRACTION ANALYSIS (Concluded)

- INCOMPRESSIBLE FLOW CODE RESULTS

MOD A (9.3796 FT. SHORTER THAN ORIGINAL)

	V/V_{sc}	% DEV.	WITH 10-FT. EXTENSION V/V_{sc}	% DEV.
WALL	6.556	+0.82	6.504	+0.02
℄	6.437	-1.01	6.500	-0.05
AVG.	6.503		6.503	
TOTAL DEV.		1.83		0.07

MOD B (15,0074 FT. SHORTER THAN ORIGINAL)

	V/V_{sc}	% DEV.	V/V_{sc}	% DEV.
WALL	6.580	1.18	6.504	+0.02
℄	6.414	-1.37	6.499	-0.06
AVG.	6.503		6.503	
TOTAL DEV.		2.55		0.08

- RECOMMEND MOD A WITH REMOVABLE SCREEN/HONEYCOMB SECTION

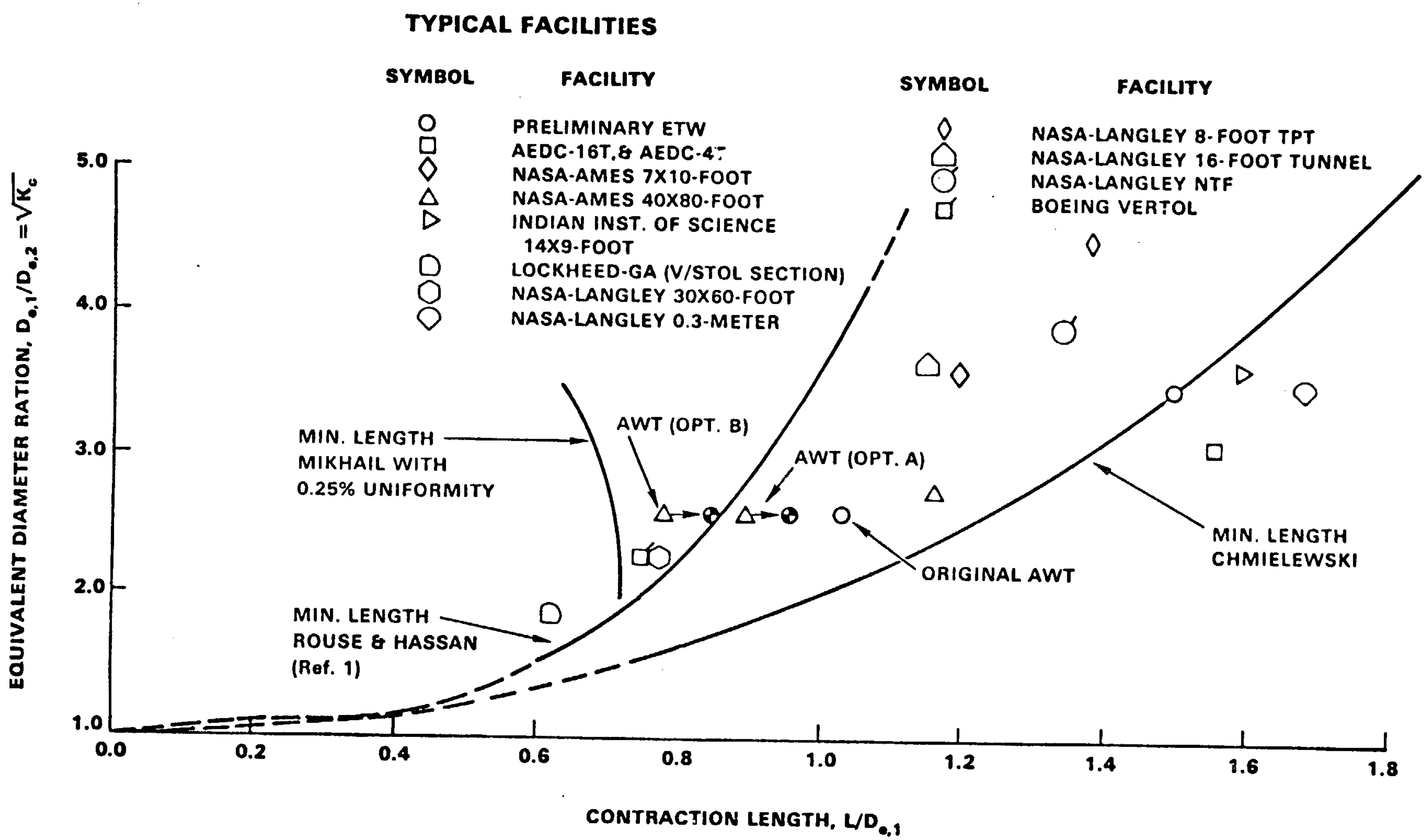


FIGURE 3. SIMPLIFIED CONTRACTION LENGTH DESIGN CURVES COMPARED TO SOME TYPICAL FACILITIES

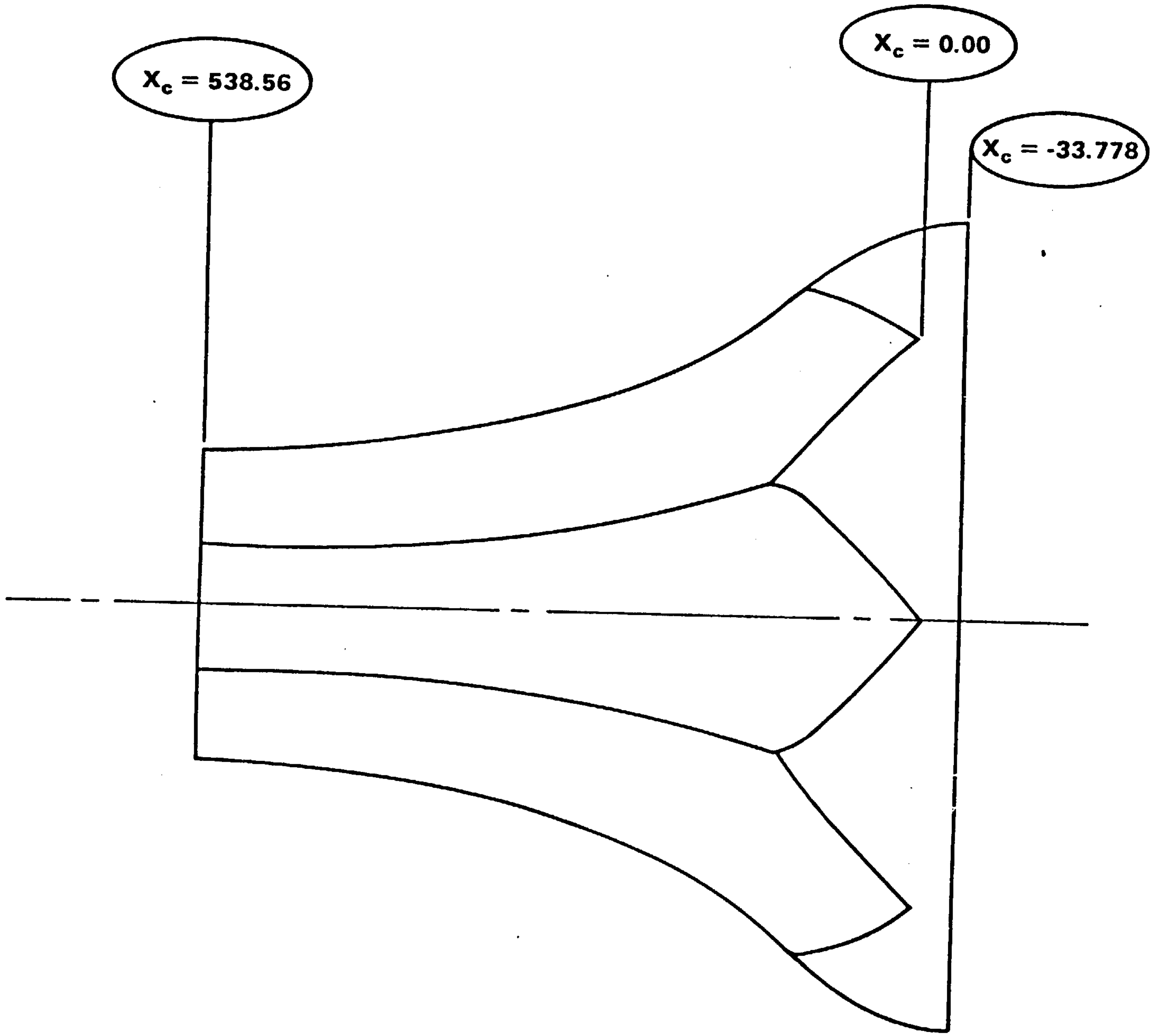
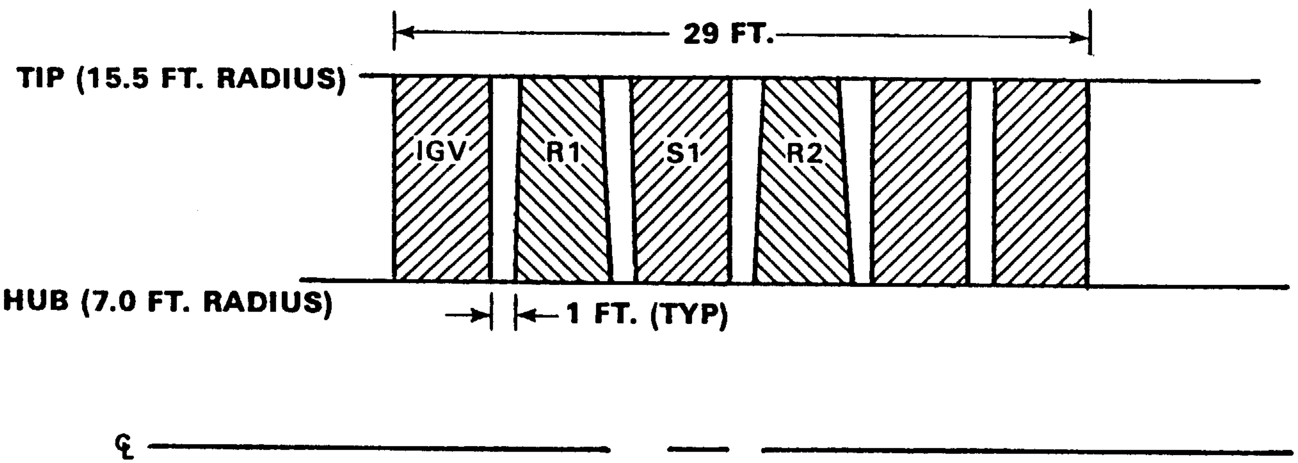


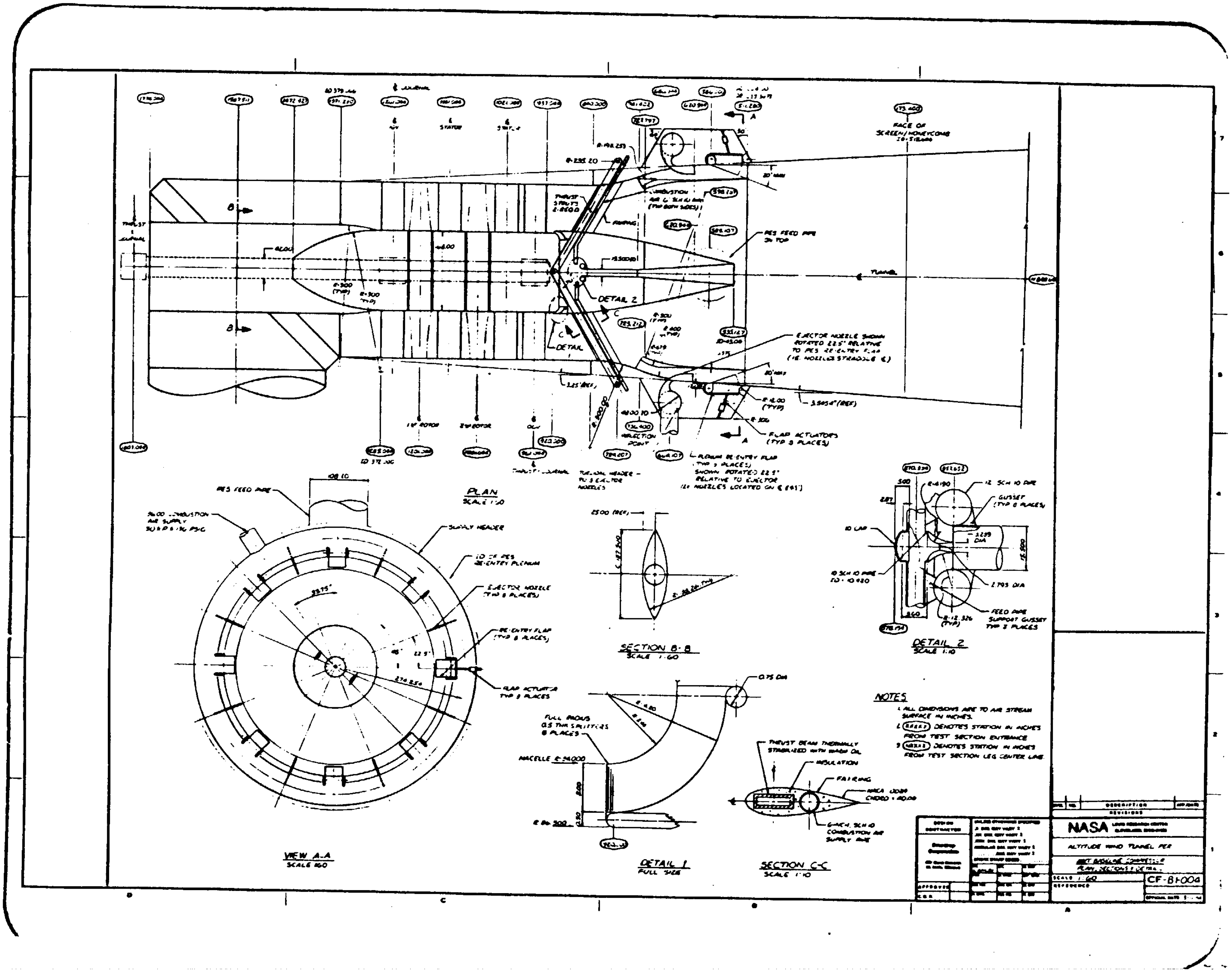
FIGURE 4. SCALE ELEVATION OF MOD A, AWT CONTRACTION

TABLE 1. AWT COMPRESSOR BLADE PATH BASELINE SPATIAL GEOMETRY

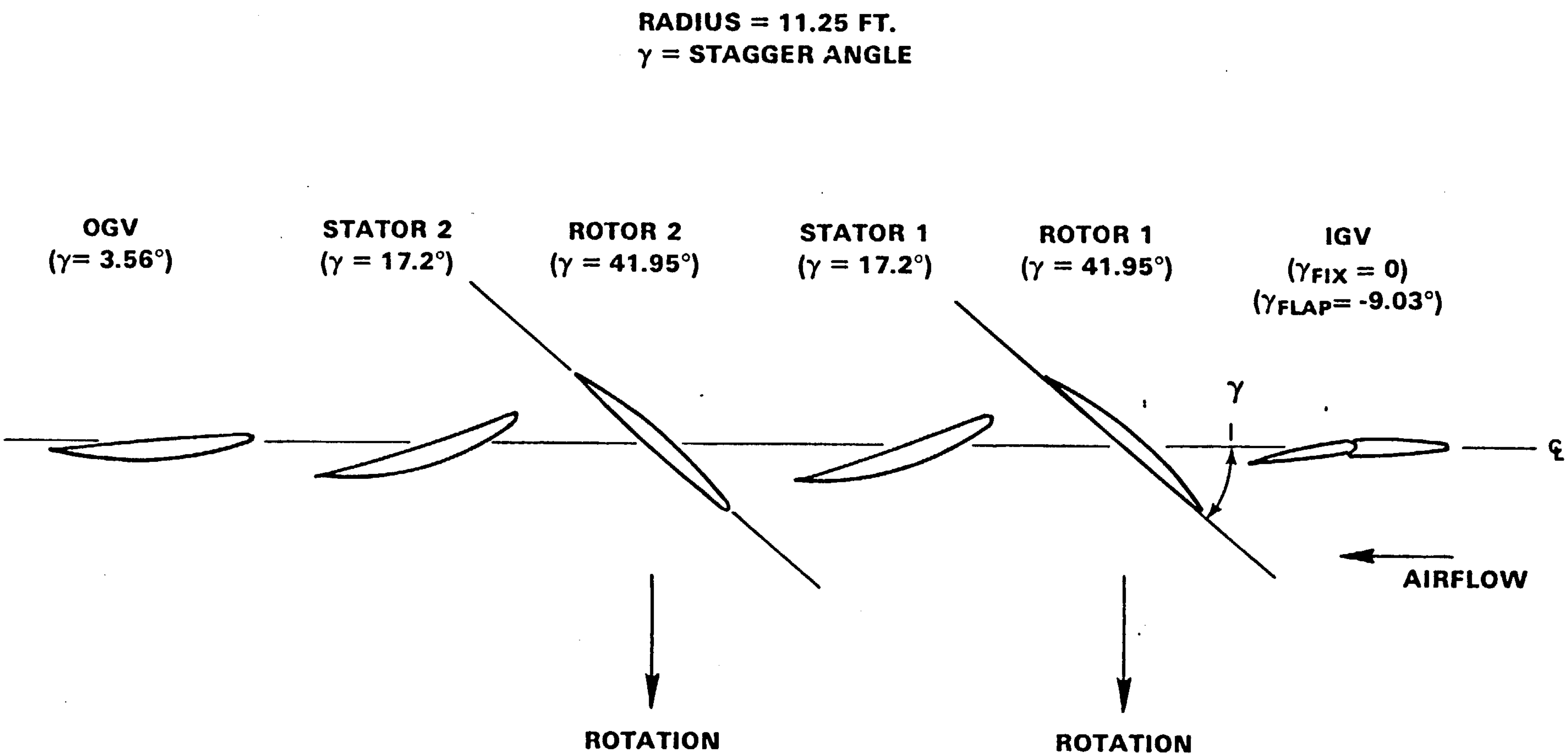
CHORD	ROTOR	IGV, STATORS, OGV
HUB	4.0 FT	4.0 FT
TIP	3.0 FT	4.0 FT

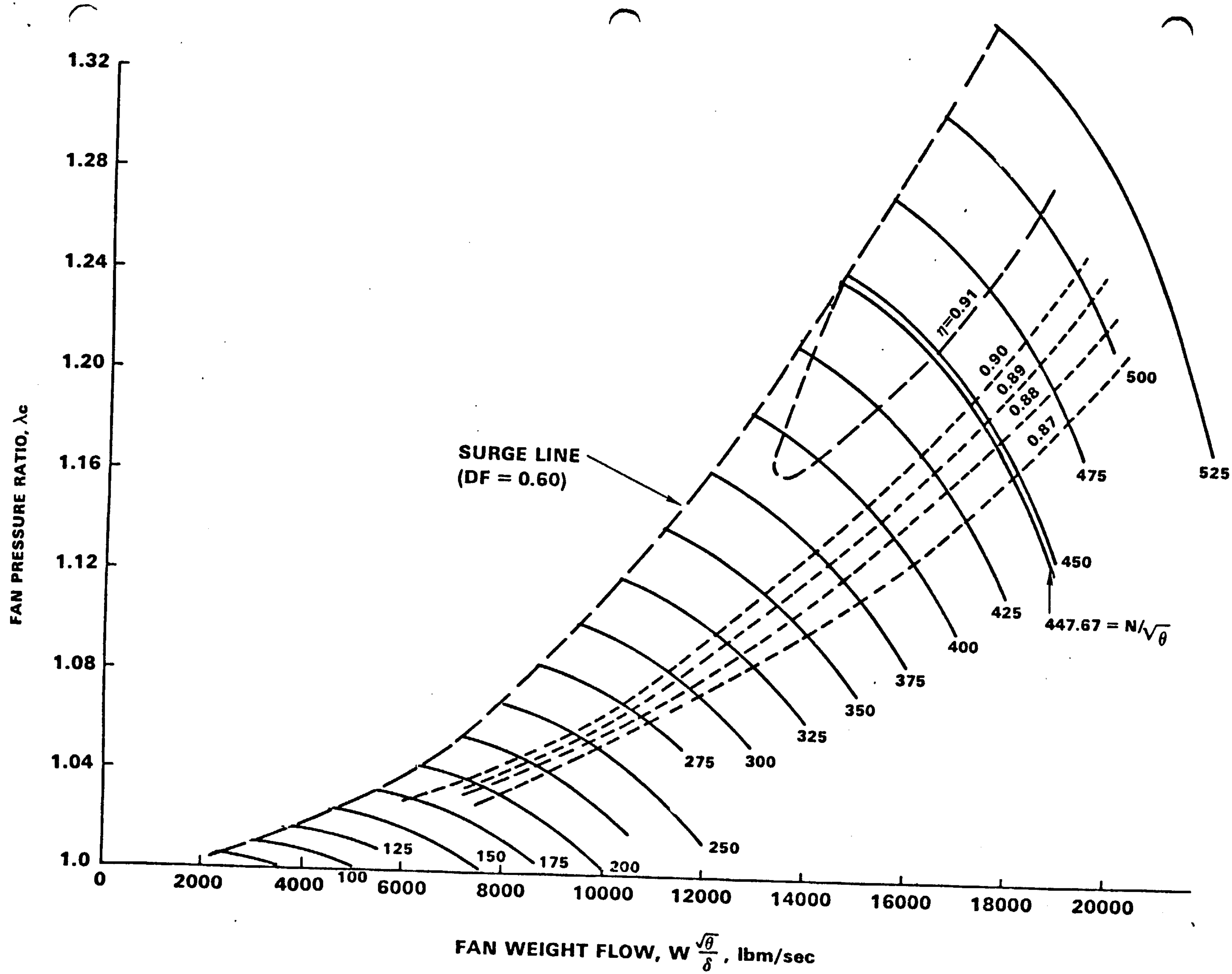


BLADE ROW	NO. OF BLADES	BLADE AIRFOIL SECIONS (CIRCULAR ARC MEANLINE) HUB	TIP
IGV	12	HUB: SvT MOD 65A010	TIP: SvT MOD 65A010
R1	17	SvT MOD 65A012	SvT MOD 65A006
S1	24	SvT MOD 65A010	SvT MOD 65A010
R1	17	SvT MOD 65A012	SvT MOD 65A006
S1	24	SvT MOD 65A010	SvT MOD 65A010
OGV	24	SvT MOD 65A010	SvT MOD 65A010


PLAN
VIEW A-A
SECTION B-B
DETAIL 2
DETAIL 1
FULL SIZE
SECTION C-C
NOTES
DETAIL 1
DETAIL 2
NASA
CF-81-004

FAN BLADE PATH





FAN PRESSURE RATIO, λc
1.32
1.28
1.24
1.20
1.16
1.12
1.08
1.04
1.0
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
FAN WEIGHT FLOW, W √θ/δ, lbm/sec
SURGE LINE
(DF = 0.60)
η=0.91
0.90
0.89
0.88
0.87
100
125
150
175
200
250
275
300
325
350
375
400
425
450
475
500
525
447.67 = N/√θ

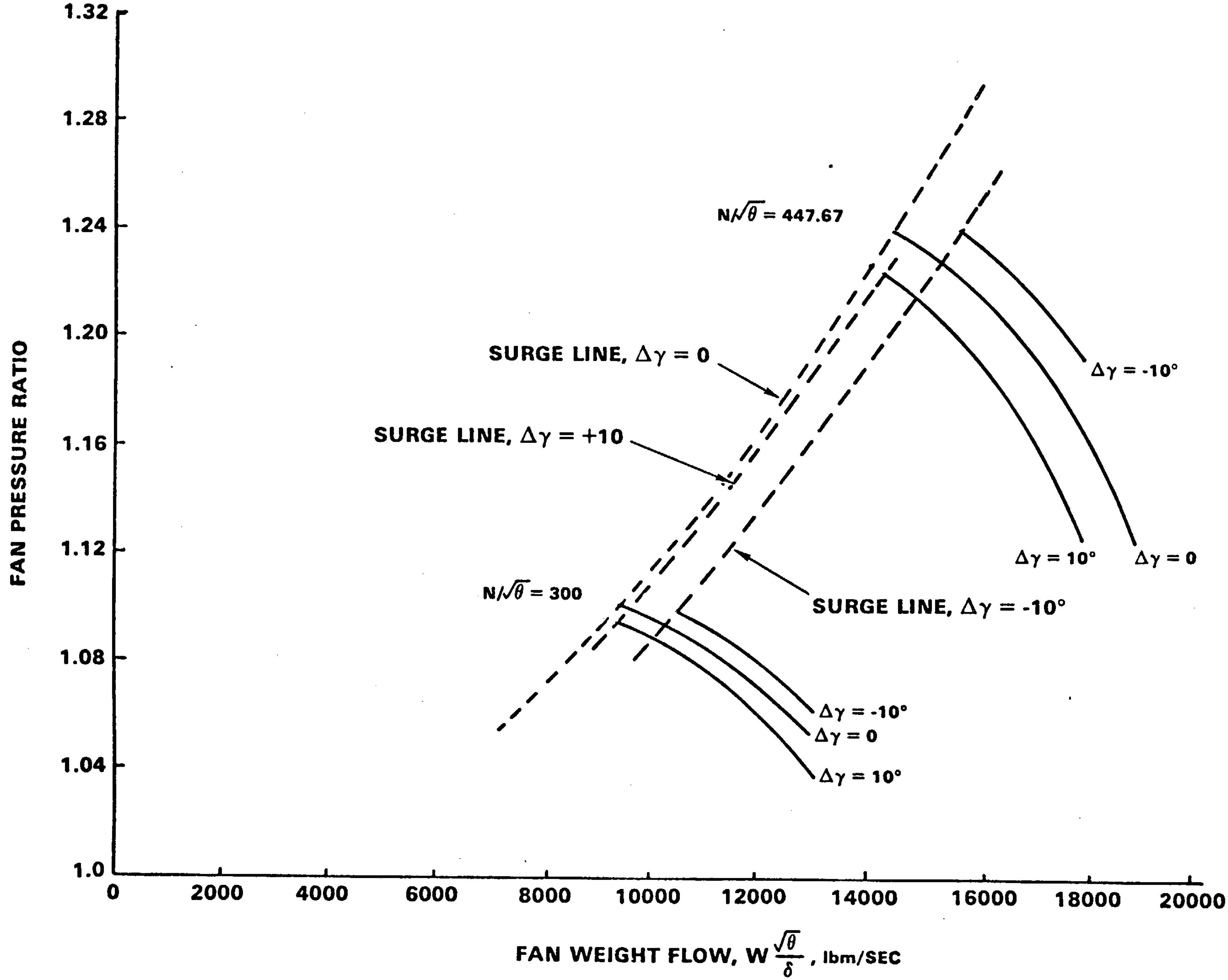


FIGURE 2. THE BASELINE AWT COMPRESSOR VARIABLE IGV CHARACTERICTICS

FAN ACOUSTIC PREDICTION METHOD

- BASED ON NASA TMX-71763
- CONSIDERS 1/3 OCTAVE BAND SPL
  - BROADBAND
  - DISCRETE TONE
  - COMBINATION TONE
- MODIFIED BOEING-AMES METHOD
- TONE CUT-OFF CRITERION INCLUDED
- CHARACTERISTIC 1/3 OCTAVE BAND SPL FOR SINGLE FAN STAGE:

$$L_c = F\left(\frac{\Delta T}{\Delta T_o}, \frac{\dot{m}}{\dot{m}_o}, M_{TR}, M_{TR_D}, RSS\right)$$

- SPL SPECTRUM:

$$SPL\ (f) = L_c + F\left(\frac{f}{f_L}\right)$$

- CORRECTION FOR INLET GUIDE VANES
- BASED ON DATA FOR 8 FULL-SCALE SINGLE-STAGE NASA-LEWIS FANS

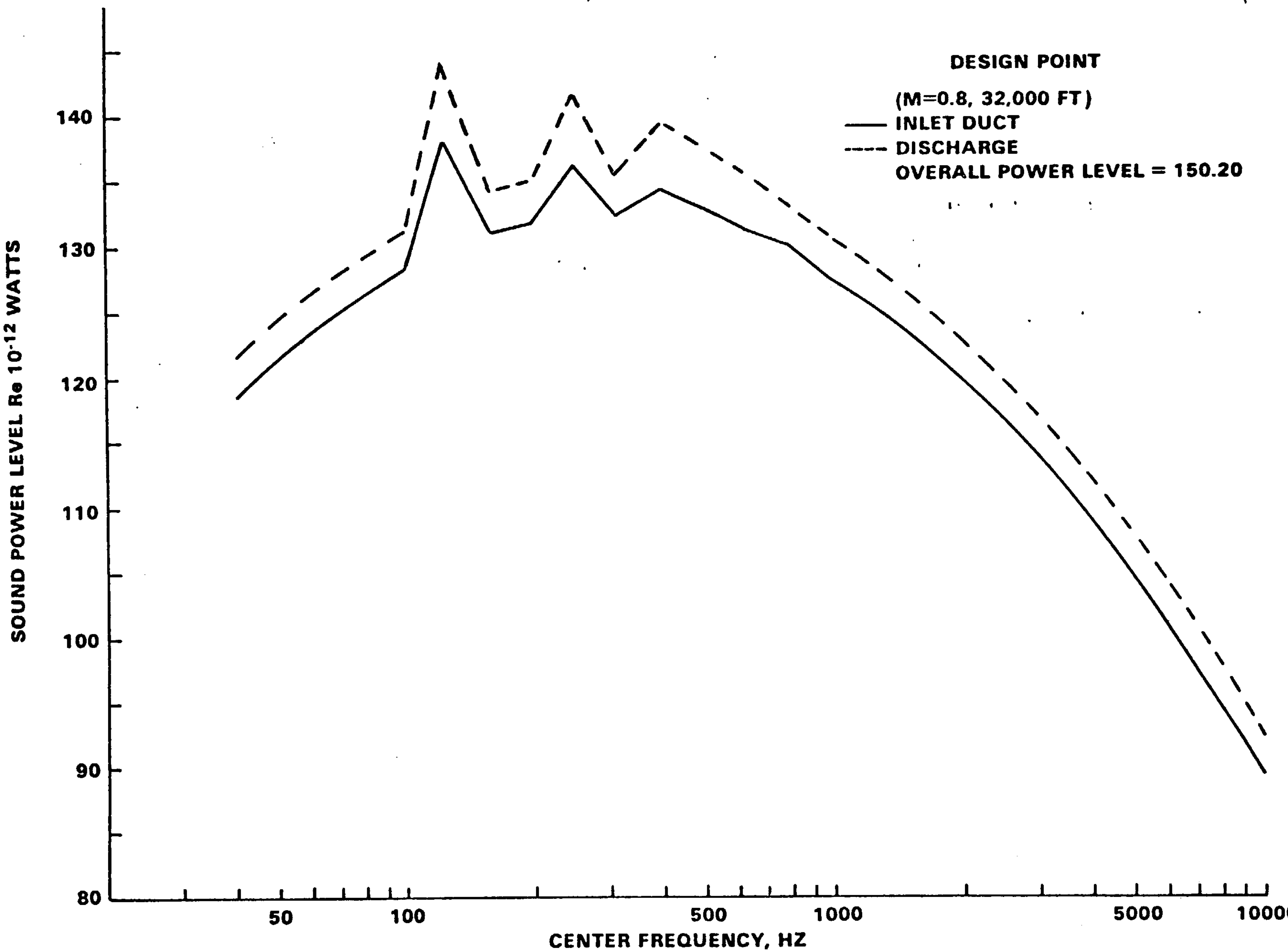


FIGURE 3. BASELINE AWT COMPRESSOR SOUND POWER SPECTRA FOR THE DESIGN POINT

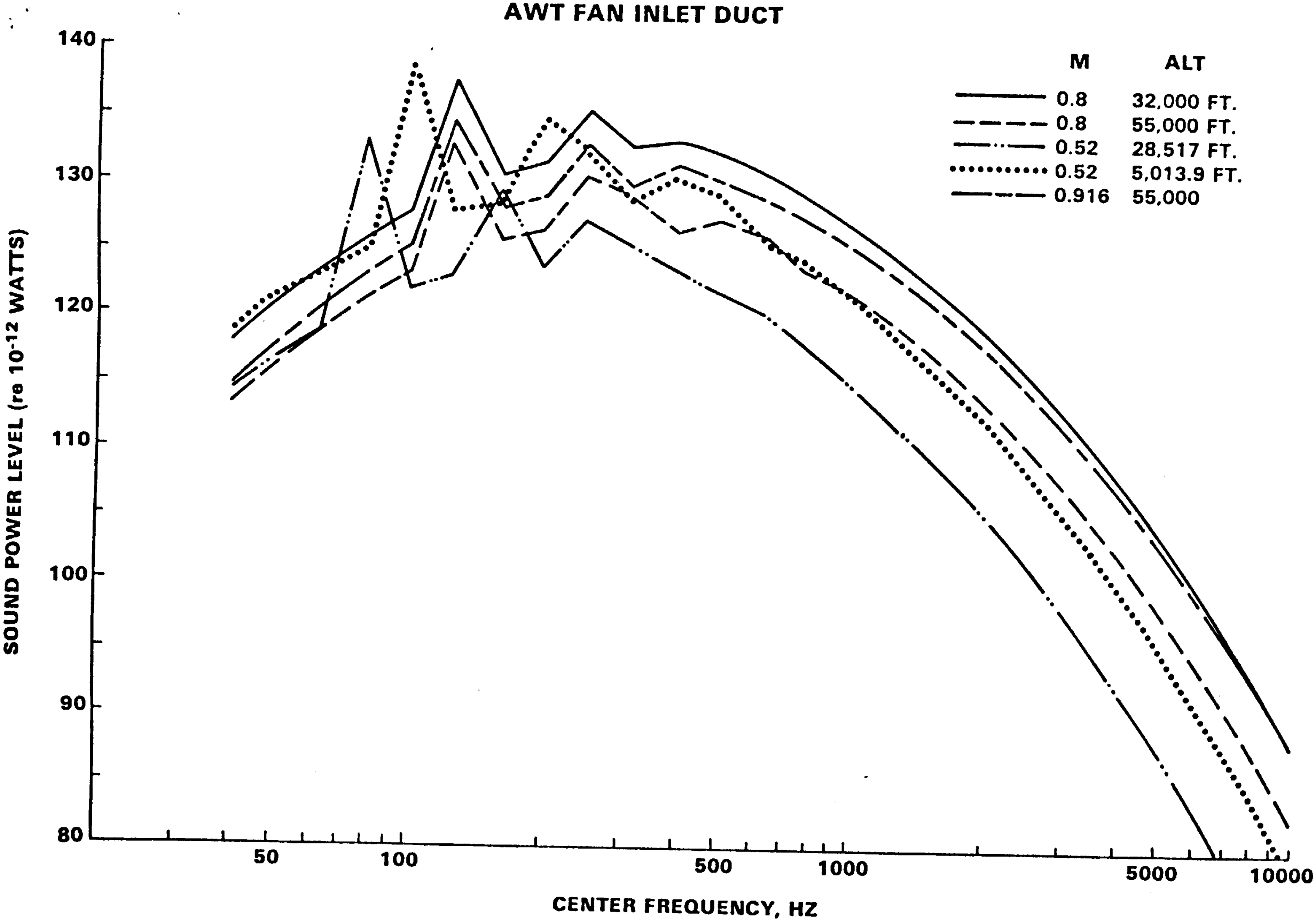


FIGURE 4. BASELINE AWT COMPRESSOR SOUND POWER SPECTRA AT THE MACHINE INLET FOR REPRESENTATIVE TEST CONDITIONS

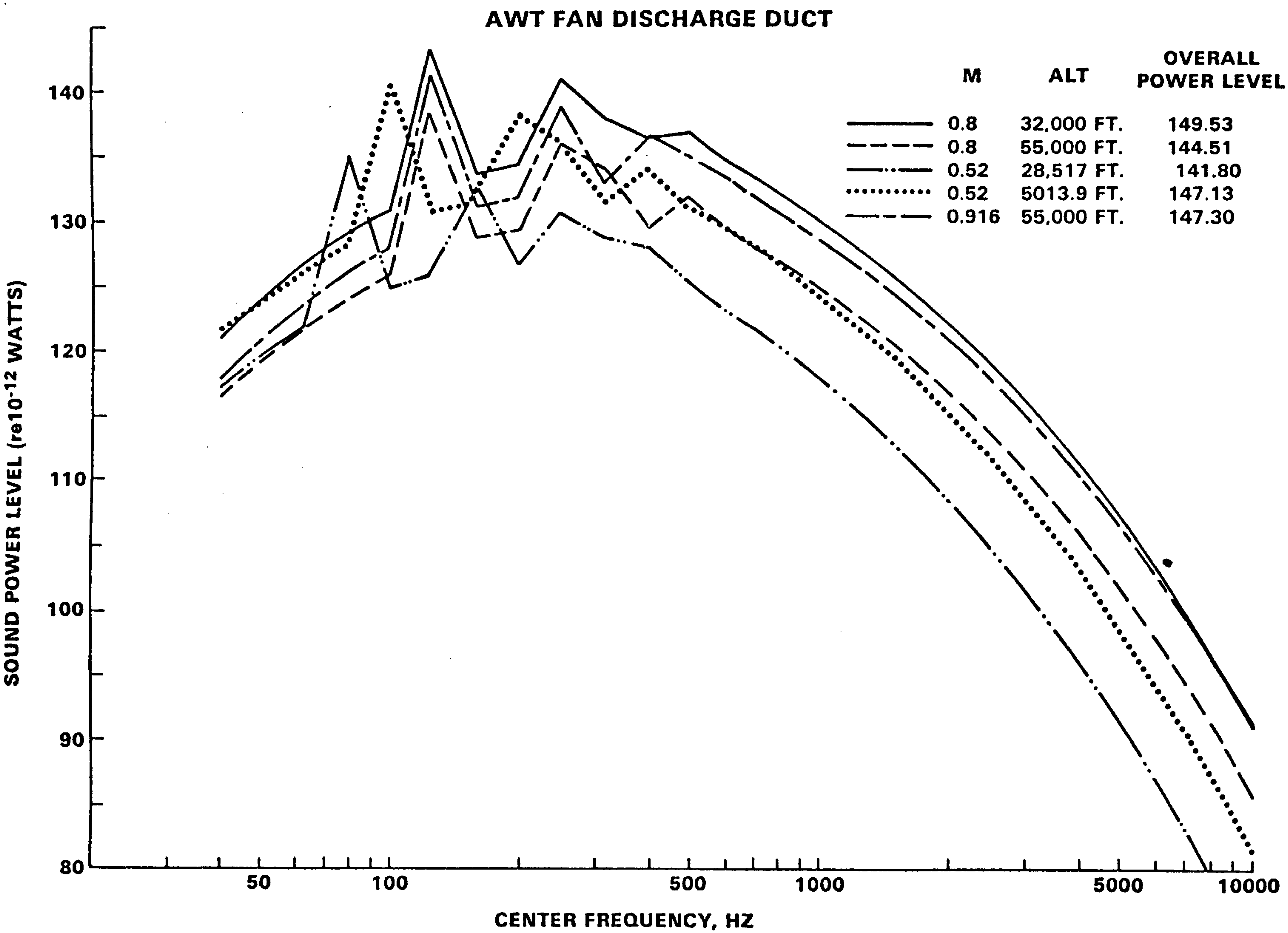
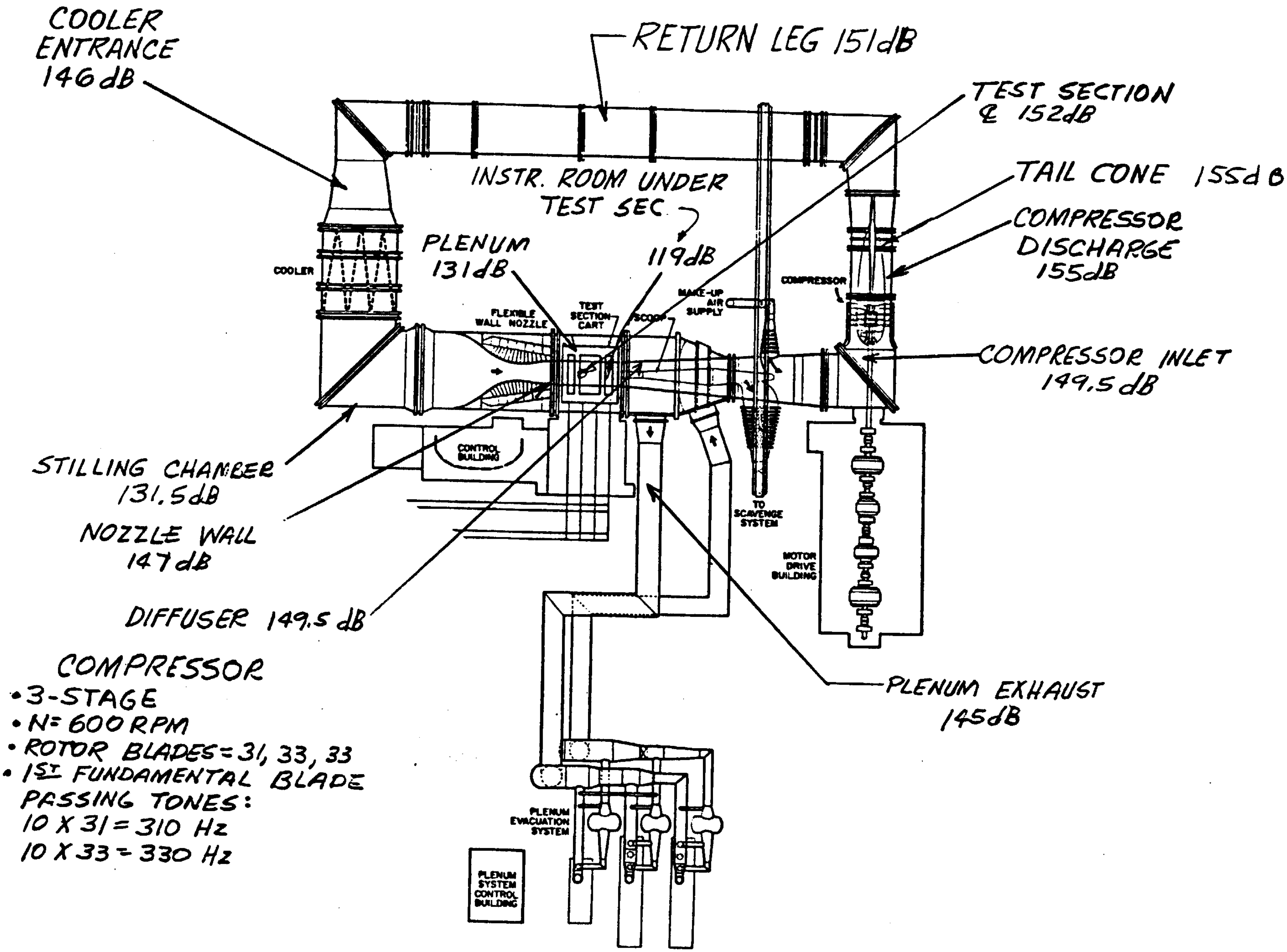


FIGURE 5. BASELINE AWT COMPRESSOR SOUND POWER SPECTRA AT THE MACHINE EXIT FOR REPRESENTATIVE TEST CONDITIONS



INTERNAL OVERALL SOUND POWER LEVELS IN TUNNEL 16T

(M = 0.75 AND P_t = 3100 PSFA)

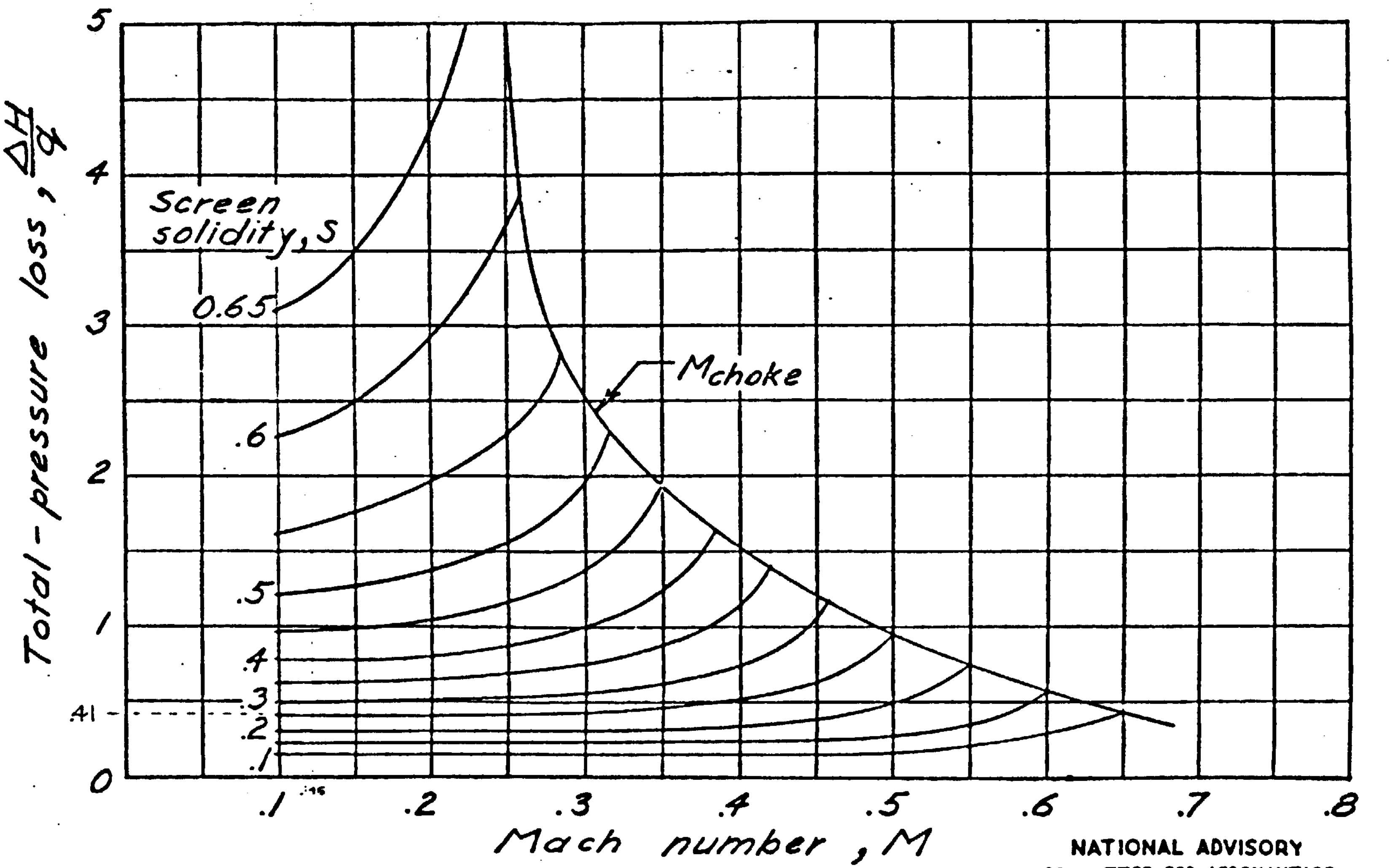


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Figure 5.- Effect of compressibility on the total-pressure loss through screens of various solidities.

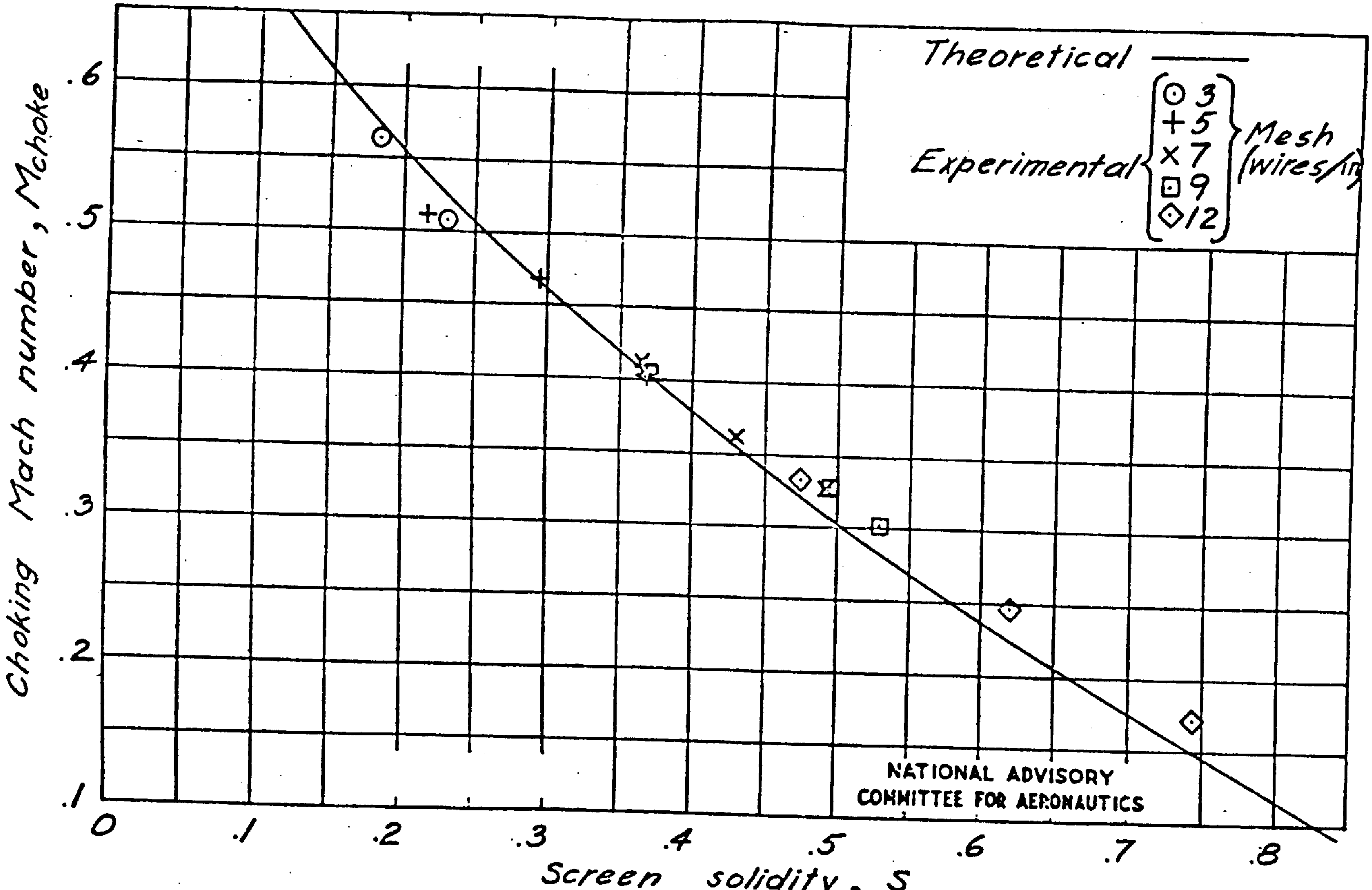

Figure 8. - Variation of choking Mach number with screen solidity.